DOCUMENT RESUME

ED 431 282 EC 307 266

AUTHOR	Langton, Anthony, Ed.
TITLE	RECREAbility: Recreation and Ability: Explore the Possibilities! Proceedings of the RESNA '95 Annual Conference (Vancouver, BC, Canada, June 9-14, 1995).
INSTITUTION	RESNA: Association for the Advancement of Rehabilitation Technology, Arlington, VA.
ISBN	ISBN-0-932101-35-6
ISSN	ISSN-0883-4741
PUB DATE	1995-06-14
NOTE	769p.
PUB TYPE	Collected Works - Proceedings (021)
EDRS PRICE	MF05/PC31 Plus Postage.
DESCRIPTORS	Adults; Appropriate Technology; *Assistive Devices (for Disabled); *Augmentative and Alternative Communication; Delivery Systems; *Disabilities; *Educational Technology; Elementary Secondary Education; Employment; Federal Legislation; Foreign Countries; Gerontology; Mobility Aids; Multimedia Instruction; Older Adults; Public Policy; *Reading Instruction; Rehabilitation Programs; Robotics; Self Evaluation (Individuals); Severe Disabilities; Special Education; Teacher Education; Transportation; Wheelchairs
IDENTIFIERS	Functional Assessment

ABSTRACT

Proceedings from this conference focus on the progress and potential of assistive and rehabilitation technology for individuals with disabilities and ways that RESNA members can make the ideas be realized. Presentations are provided on the following topics: (1) service delivery and public policy issues; (2) personal transportation; (3) augmentative and alternative communication; (4) quantitative functional assessment; (5) special education, including multimedia for assistive technology training and recruitment, interface specification for children with severe physical disabilities using robotics or other assistive technology, documenting assistive technology use, and the use of observation via audiotapes and computer spreadsheets to improve oral reading; (6) technology transfer; (7) sensory aids; (8) wheeled mobility and seating; (9) electrical stimulation; (10) computer applications; (11) rural rehabilitation; (12) assistive robotics and mechatronics; (13) job accommodations; (14) information networking; (15) gerontology; (16) international appropriate technology; (17) personal assistance services and assistive technology; (18) universal access; (19) cognitive disability and technology; (19) rehabilitation engineers; (20) development toward a direct brain interface to control assistive technologies; and (21) Whitaker Student Scientific Paper Competition. Presentations include references. (CR)

****
* Reproductions supplied by EDRS are the best that can be made *
* from the original document. *
****

EC

ED 431 282

PROCEEDINGS

RESNA '95 RECREAbility

U.S. DEPARTMENT OF EDUCATION
Office of Educational Research and Improvement
EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
☑ This document has been reproduced as received from the person or organization originating it.
☐ Minor changes have been made to improve reproduction quality.
- Points of view or opinions stated in this document do not necessarily represent official OERI position or policy.

PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY
Horner
TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)
1

VANCOUVER
CANADA

June 9-14, 1995

BEST COPY AVAILABLE

PROCEEDINGS
# of the
RESNA '95
Annual Conference

RECREAbility
Recreation and Ability:
Explore the Possibilities!

June 9-14, 1995

Vancouver Trade
& Convention Center

Vancouver, BC, Canada

Anthony Langton
Editor

Phil Mundy
David Cooper
Conference Co-Chairs

RESNAPRESS

Proceedings of the RESNA '95 Annual Conference
Vancouver, BC, Canada
June 9-14, 1995

Volume 15
ISSN 0883-4741
ISBN 0-932101-35-6

Copyright © 1995
RESNA

All rights reserved. This book or any part thereof may not be reproduced in any form without the permission of the publisher.

RESNAPRESS

1700 North Moore Street, Suite 1540
Arlington, VA 22209, (703) 524-6686

Printed in the United States of America
Dependable Printing Company, Inc.

Foreword

Access to Technology - Anyone, Anywhere

RESNA has been a long time leader in providing direction for the development and provision of assistive technology in North America and worldwide. Each year we meet to exchange our ides and our products, and the results that benefit persons with disabilities around the world. We exchange information, promote the development of programs and policies, and we establish the means to ensure quality and appropriateness. This program is a reflection of the efforts of our diverse group of technical, clinical and research oriented people. Unseen are the efforts of the various committees and the wealth of information that is exchanged in informal sessions and in the exhibit hall. The varied venues for exchange are a reflection of our continuing commitment to address the issues surrounding individuals that can benefit from assistive technologies.

RECREAbility: Recreation and Ability - Explore the Possibilities!! The focus for RESNA '95 is recreation and leisure activities for all! Sports, recreation, and leisure activities are important in all our lives. We are going to give you a close look at recreation programs and adapted equipment throughout the conference and in the Recreation Centre in the Exhibit Hall. Be sure to start Monday, Tuesday, and Wednesday with the morning workout in the Recreation Centre.

Research Symposium The Research Symposium is new this year and it is to be continued in the future. This year we will explore recent accomplishments and the current state of the art in the development of direct brain interfaces to control assistive technologies.

Manufacturer Workshops Also new this year are a series of workshops presented by equipment manufacturers. These are held concurrently with the Instructional Courses and Morning Seminars.

4th Night Fest The social highlight of the conference starts at 6:00p.m. on Monday night in and around the Exhibit Hall. With festive food and a variety of roving entertainers including mimes, jugglers, and many musicians, *4th Night Fest*, will run up until Dance Nite at 9:00p.m. with the swinging Jim Byrnes Band Spinal Cord.

On behalf of the RESNA Board of Directors and this year's Local Arrangements Committee, we welcome you to Vancouver for the 1995 RESNA Annual Conference. Explore the Possibilities!

Phil Mundy and David Cooper
RESNA '95 Conference Co-Chairs

Clifford E. Brubaker
RESNA President

Preface

Welcome to RESNA '95. This year's theme, "RECREAbility," sets the tone for the most ambitious conference that RESNA has offered. A full array of instructional courses and morning seminars, special sessions, exhibits, and the new manufacturer workshops, offer a backdrop for an expanded scientific program. Within the scientific program there will be over 250 platform, interactive, and computer paper presentations, highlighted by the first annual Research Symposium which will focus on direct brain interface control of assistive technologies.

The Proceedings of the RESNA Conference is an attempt to capture at least a portion of the energy and information that will be exchanged during the activities and events which make up RESNA '95. Highlighted this year will be recreation and leisure applications, along with the familiar content of the twenty Special Interest Groups that form the scientific core of the RESNA Conference. The Proceedings should help to contribute to the growing body of professional literature and information on rehabilitation technology applications to assist individuals who have disabilities which somehow restrict their activities.

We hope that the Proceedings will also capture some of the spirit and enthusiasm that will be present during the time in Vancouver. Conference Co-Chairs, Phil Mundy and David Cooper, have organized one of the best Local Committees that RESNA has ever had. The work of Mary Binion and members of the 1995 Meetings Committee, along with continued support of Jim Geletka, Susan Leone, Terry Reamer, and other RESNA staff, make the RESNA Conference possible. Through their efforts, participants will be able to experience the most comprehensive rehabilitation technology conference available while enjoying the sights, sounds and tastes of one of the most beautiful cities in North America.

Enjoy!

Anthony Langton
Chair, Scientific Program and Special Interest Groups

RESNA Board of Directors

Executive Committee

President

Clifford E Brubaker, PhD
University of Pittsburgh School of Health/Rehab Sciences

President Elect

Albert M Cook, PhD PE
University of Alberta Faculty of Rehabilitation Medicine

Secretary

Elaine Trefler, OTR Med FAOTA
University of Pittsburgh School of Health/Rehab Sciences

Treasurer

Michael Silverman
Pin Dot Products

At Large Members

Rachel Wobschall, MIM
Minnesota Star Program
Donald R McNeal PhD,
Rancho REC

Immediate Past President

Gregg C Vanderheiden, PhD
University of Wisconsin Trace R&D Center

Board of Directors

Mary Binion MA, Ohio Resource Center for Low Incidence & Severely Handicapped
David Cooper MS Kin, Sunny Hill Hospital
Alexandra Enders OTR, University of Montana
Jan C Galvin, Galvin Group Ltd
Paul N Hale Jr PhD PE, Louisiana Tech University
David F Law Jr, Woodrow Wilson Rehab Center
Jean Minkel MA PT, Helen Hayes Hospital
Phil Mundy, BCIT Technology
Kathleen R Riley BSPT, Durham, North Carolina
Carol Sargent BSEE OTR/L, Lake Forest, Illinois
Susan Johnson Taylor, Shepherd Spinal Center
Gerald Weisman, MS, Vermont REC
Jody J Whitmyer, Whitmyer Biomechanix Inc

Past Presidents

Douglas A Hobson PhD, University of Pittsburgh School of Health/Rehab Sciences
Richard A Foulds PhD, AI duPont Institute ASEL
C Gerald Warren MPA, C Gerald Warren & Associates
Sheldon R Simon MD, Ohio State University
Dudley S Childress PhD, Northwestern University
Morris Milner PhD PEng CCE, Hugh MacMillan Rehabilitation Centre
Donald R McNeal PhD, Rancho Los Amigos REC
Colin A McLaurin ScD, University of Virginia REC
James B Reswick ScD, National Institute on Disability & Rehabilitation Research

Conference Organizing Committee

Conference Chairs
Phil Mundy, BCIT Technology Centre
David Cooper, Sunny Hill Centre for Children

Meetings Committee Chair
Mary Binion, Ohio Resource Center
Accessibility
Aimee Luebben, University of Southern Indiana
Computer Tech Lab
Denis Anson OTR, Univ Washington
Exhibits
Kevin Caves, Rancho REC/CART
Instructional Program
Carol A Sargent BSEE OTR/L, Lake Forest, IL
Publicity & Exhibits
Corrine Carriere, Boulder, CO
Research Symposium
Simon P Levine PhD, University of Michigan
Scientific Program
Anthony J Langton MS, South Carolina Voc Rehab
Student Design Competition
David F Law Jr, Woodrow Wilson Rehab Ctr
Whitaker Student Scientific Paper Competition
Simon P Levine PhD, University of Michigan
Video Theater
Stanley Cronk PhD, University of Tennessee-Memphis

Conference Management
James R Geletka, Executive Director
Susan P Leone, Meetings Director
Terry Reamer, Conference Coordinator
Ellie Klos, Registrar

Vancouver Local Arrangements Committee

Garet Anderson, Scottsdad
Elaine Antoniuk, Sunny Hill Health Centre for Children
John Armstrong, Motion
Nancy Balcom, Motion Specialties
Barbara Barringer, BC Medequip
Jan Bednarczyk, Royal Columbian Hosp
Bonnie Blacklock, Rec Integration
Larry Boden, Vancouver
Frederica Bowden, Vancouver
Fran Boyd, Sunny Hill Centre for Children
Michael Brooks, TETRA Society
Andrew Brule, Sunny Hill Health Centre for Children
Jennette Calderone, BC Rehab
Doug Campbell, BC Medequip
Wayne Carpenter, Care Medical
Shirley Cazalet, SET BC
Darcy Cooper, Barnaby Health Department
Simon Cox, Kinsmen Rehab Foundation
Wayne Deer, Vancouver
Ian Denison, BC Rehab
Jackie Dupuis, Sunny Hill Health Centre for Children
Kathy Ellis, Kinsmen Rehab Foundation
Jane Fontein, Jay Medical
Robert Ford, Ford Laboratories
Gail Gabel, The Gabel Group
Peter Graystone, Vancouver
Tracy Groshak, BC Medequip
Scott Hamilton, Vancouver
Gordon Harris, Gus Communication
Joe Higgins, Motion 2000
Candice Hitch, Sunny Hill Health Centre for Children
Norm Horsfield, BC Rehab
Dan Ipsen, BC Medequip
Randy Keith, Western Rehab
Catrina Kelly, Vancouver
Shawn Laari, Sport & Fitness for Disabled
Leeta Liepins, BC Medequip
Marion MacIsaac, E&J Canadian Ltd
Judy Marolla, BC Medequip
Dianna Mah Jones, BC Rehab
Marg Martin, Queen Alex-Victoria
Mary Morrison, BC Rehab Society
Joanne McKechnie, Arbutus Society
Sylvia Mosterman, Suitable Design
Doug Nutting, Recreation Integration
Carol Redekopp, BC Rehab
Kathleen Reidy, E&J Canadian Ltd
Richard Robinson, HMI Computer Group
Donna Rodman, Ability Arts Centre
Peter Scott, The Rehab Shop
Gerri Sing, Tourism Vancouver
Adrian Smyth, BC Medequip
Bob Stickney, Sunny Hill Health Centre for Children
Janette Stone, BC Rehab
Maureen Story, Sunny Hill Health Centre for Children
Gary Tennany, Sunny Hill Health Centre for Children
James Watzke, Simon Fraser University
Geoffrey Webb, Daedaelus Technologies
Joanne Yip, BC Rehab

RESNA Gratefully

...acknowledges conference support from the following PATRONS

Apple Computers Office of Special Education
for support of the Computer Tech Lab
*B.C. Ministry of Skills, Training and Labour**
for interpreting services
*B.C. Ministry of Employment and Investment**
for dance night adapted technology demo
*B.C. Rehabilitation Society**
*Daedalus Technologies, Inc.**
*Doncaster/B.C. Medequip Ltd**
Everest & Jennings, Inc
*G.S. Gabel & Associates Ltd**
Hear Our Voices
Insurance Corporation of B.C.
for Keynote Speaker support
Invacare Canada
*Motion Specialties B.C. Ltd**
*Phil Mundy Engineering Services**
Prentke Romich Company
Quickie Designs
for Recreation Centre floor
Status of Disabled Persons Secretariat
Semantic Compaction Systems
Southwestern Bell Telephone Company
The Mark Anthony Group
for providing wine for conference promotion
*TIGER c/o Kinsmen Rehab Foundation**
*Vancouver Trade and Convention Centre**
Whitaker Foundation
Wilson International

*Initial Conference Supporter (organizations who contributed to early stage efforts in bringing the RESNA Conference to Vancouver).

...AND recognizes the assistance of the following organizations

Assistive Devices Research & Development Project
Sunny Hill Health Centre for Children
Arbutus Society
B.C.I.T. Technology Centre
BC Medequip
B.C. Rehabilitation Society
B.C. Sport & Fitness Council for the Disabled
Care Medical
E&J Canadian Ltd
Ford Laboratories
Gus Communication
Jay Medical
Kinsmen Rehabilitation Foundation
Motion 2000
Ohio Resource Center for Low Incidence & Severely Handicapped
Queen Alexandra Centre for Children, Victoria
Rancho Los Amigos Medical Center REC and CART
Recreation Integration of B.C.
Scottsdad
SET BC
Simon Fraser University
South Carolina Vocational Rehabilitation Department
Suitable Design
TETRA Society
The Gabel Group
The Rehab Shop
University of Southern Indiana
University of Tennessee-Memphis
University of Washington
Western Rehab
Woodrow Wilson Rehabilitation Center

TABLE OF CONTENTS

SIG-01 Service Delivery & Public Policy

Information Use and Outcomes for Clients in Seating Assessment Clinics 2
Development of a Bed Overlay to Control Extensor Tone, Improve Respiration, and Reduce Mattress Interface Pressures 5
The Alberta Experience in Recycling Durable Medical Equipment 8
Development of a Care Safety Restraint for Children who Escape Commercial Systems 11
Human Diversity and Assistive Technology Service Provision 14
A Study of the Proximal Stabilization Program: Its Effect on Gait and Range of Motion 16
Building School District Capacity for Assistive Technology Integration 19
Inter-Agencies Service Delivery Model, Step 1 22
Impact Analysis of the Advocacy and Information and Referral Components of a Service System 25
Transition to Community Living: An Assessment of Assistive Technology Needs and Costs 28
An Assistive Technology Program in Response to OBRA-87 31
The Rehabilitation Team: A Systematic Approach for Use of Technology in Vocational Rehabilitation Services 34
Accommodations for Persons with Mental Disabilities 37
The Stair Assist System - A Clinical Trial 39
Videoconference Technology: Exploring an Alternate Service Delivery Model in Health Care 42
Research in Leisure and the Family 45
From Hospital to Community: Opportunities for Meaningful Activity through the Development of Recreation Outreach Networks 47
Accessible Kayaking - The Next Generation: To Paddle Like No One has Paddled Before! 50
An Analysis of One Rehabilitation Engineer's Work Considering Job Accommodation Costs and Consumers Served 53
A Systematic Interdisciplinary Assessment Model 56
Achievement of Physical Therapy Goals as a Result of Assistive Technology Use 59
State of the Heart - Assistive Technology in Europe 62
Accessible Housing in Europe: Policies and Results 65
Quality Management Systems in Wheelchair Prescription 68

SIG-02 Personal Transportation

Whiplash Injury Risk to People with Disabilities Traveling in Wheelchairs 72
Change of Handling and Rollover Stability of Vans due to Body Raise 75
Universal Tiedown and Occupant Restraint System for Mobility Aids 78
Evaluation of Powered Lifts for Commuter Railcar Access 81
Wheelchair User Stability during Simulated Driving Maneuvers 84
Securement of wheelchairs in Motor Vehicles: Is it Time for a Universal Solution? 87

SIG-03 Augmentative & Alternative Communication

Reaching for the Stars:. A Theater Experience 92
JustType - Efficient Communication with Eight Keys 94
Singing on the Multivoice 97
A Comparison of the Introduction of Voice-Output AAC Devices with Two School-Age Children with Athetoid Cerebral Palsy 100

Multimodal Communication Systems: Enhancing Interaction Skills for AAC Users 103
A Headcontrolled Dynamic Display AAC System 106
Evaluating the Use of Talksbac with Non-Fluent Dysphasic Adults 109
Team Perceptions of Dynavox Users - Survey Results of Functional Nontechnical and Technical Communication Use 112
AAC Strategies for Progressive Pahasia without Dementia: Case Study 115
Motivation and the Myoswitch: The Development of a Myoelectric Switch for ACC 118
Developing an Interface for an Augmentative Communication Device with Multiple Vocabulary Selection Modes 121
A Lexical Database for Intelligent AAC Systems 124
Validating Quantitative Models of User Performance with Word Prediction Systems 127
Integrated Access to Powered Mobility, Tilter, Computer, and Environmental Control 130
The Cost X Performance Tradeoff for Voice Output AAC Aids: Is it Real? 133
Communication Effectiveness in Recreation Activities by Augmentative Communication Users in British Columbia 136
The Amount of Information Transmitted by the Residual Functions in Motor-Disabled Person 139
Assessing Picture-Related Skills Using Lascaux 142

SIG-05 Quantitative Functional Assessment

Integrated Video and Computerized Functional Assessment 146
Training Rehabilitation Engineers to Meet Anticipated Future Needs 149
The Effect of a Lifting Belt on the Functional Capabilities and 3-D Trunk Motion Parameters during a Fatiguing Exercise 152
Compression is Superior to Evacuation for Cough Assist 154
A Hybrid intelligent System for Classification of Dysphagia 156
A Quantitative Evaluation of Upper Limb Motor Function in Children with Physical Disabilities 159
Identifying Essential Functions: An Additive Value Function 162
Risk Factors for Future Disability Due to Low Back Injuries 165
Gait Activity Monitor for Long-Term Measurement of Ambulatory Function 168
A Bonding Technique for Strain Gage Attachment on Polypropylene Orthosis 171
A Compliance-Independent Pressure Transducer for Biomedical Device/Tissue Interfaces 174
Biomechanical Evaluation of Spasticity 177
The Effect of Wrist Posture on the Grip Strength of Persons with Cerebral Palsy: Implications for Tool and Task Design 180
Van Nes Anatomical and Prosthetic Joint Motion and Co-Function: towards Design Modification of the Van Nes Prosthesis 183
A Method for Comparison of Contiguous Ground Reaction Force Data and Single Stance Ground Reaction Force Data 186
Pilot Study on Ankle-Foot Orthosis Loading During Gait to Determine the Stress Distribution for Finite Element Modelling 189
Assessment of Efficacy of Silicone Gel-Filled Shoe Insoles for Plantar Pressure Relief 192
A Manual Wheelchair Exercise Device with Powered Assistance 195

SIG-06 Special Education

Multimedia for Assistive Technology Training and Recruitment: Two CD-ROM Training Programs 200
Interface Specification for Children with Severe Physical Disabilities using Robotics or Other Assistive Technology 202
Documenting Assistive Technology Use in Florida 205
The Use of Self Observation via Audiotapes and Computer Spreadsheets to Improve Oral Reading 207

SIG-07 Technology Transfer

Advanced Wheelchair Electronics Controller: A Preliminary Pilot Evaluation Report 212
Product Commercialization - New Silicone Ability Switches for the Disabled 215
Robust Environmental Big Button Switches 217
CAD/CAM for Prosthetics: Successful Technology Transfer 220
Product Development through Regional International Co-Operation: A Nordic Approach 223
A Forum for Improving Assistive Technology Product Development 225
Improving Technology Transfer: Three Priority Areas 228

SIG-08 Sensory Aids

Pointing Keyboard and Tactile Feedback System for Blind Computer Access 232
Stimulus Derived Perceptual Dynamics in Tactile Reading 235
Away From the Maddening Crowd 238

SIG-09 Wheeled Mobility and Seating

Interface Mechanics in Prosthetics: A System for Analysis 242
Long Term Results of Postural Positioning 245
Indepth Assessment of a Postural Positioning Program 248
Seating and Mobility for a Ventilator-Dependent Muscular Dystrophy Adult 251
Custom Head Support for a Pediatric Quadriplegic with Asymmetrical Neck Tone 254
A Wheelchair Modification to Assist with Pressure Relief Performance in Low Level Quadriplegia 257
Evaluation of a Powered Wheelchair Evaluator 259
Tracking System for Seating and Wheeled Mobility Equipment in a Rehabilitation Center 262
Standardization of Electrical Loads Imparted on Powered Wheelchair Drive Systems by Double Drum Test Machines 264
Evaluation of a Laser Displacement Sensor for use in Special Seating 267
The Soto Wheelchair 270
The Effect of the Folding Mechanism on the Slack of the Backrest for Vertical Folding Wheelchairs 273
Design of a Lifting Device for People with Muscular Dystrophy 276
A Buggy for Taking Disabled Children Over Sand 279
Playing Video Games for Fitness and Fun with any Wheelchair 282
A New Device for Continuous Measurement of the Lumbar Spine 285
Immediate Improvements in Wheelchair Mobility and Comfort with use of the Adjustable Back Support Shaping System 288
Modification of the Local Effective Stiffness of Seating Foam by Hole Drilling 291

Mechanical Effects of Coatings on Cushioning Foams 294
A Biomechanical Approach to Seat Cushion Comparison in Wheelchair Users 297
Reliability of Contours of Positive Molds Following Seating Simulation 300
A Reusable Mold for Custom Contour Cushion Manufacturing 303
Wheelchair Crash Structural Computer Model 306
Crash Response of Wheelchair Occupants with Different Sitting Postures in Transport 308
The Affects of Shoulder Belt Anchor Position on Wheelchair Transportation Safety 311
Potential Hazards of Wheelchair Lap Belts 314
Evaluation of a Program to Teach Seating Clinics How to Build Custom Care Seats 317
Development of a Cognitive Assessment Battery for Evaluating Readiness for Powered Mobility 320
An Integrated Pilot System to Increase the Autonomy of Disabled and Elderly People in Mobility and Manipulation 323
Concept and Implementation of a Force Feedback Active Joystick 325
A Flexible Joystick Handle 328
A Polyvalent Control Interface 331
Wheelchair Related Accidents and Malfunctions 334
Low Back Pain and Whole Body Vibration Exposure for Wheelchair Users 337
Tire Rolling Resistance, Ride Comfort & Flame Hazard 340
Adding Loads to Manually Propelled Wheelchairs: Computer Modelling Results of the Effect on Static Stability 343
Experimental Location of the Axis of Rotation for Rear Stability of Wheelchairs With and Without Camber 346
Static Stability Testing of Stand-up Wheelchairs 349
Smartwheel: Development of a Digital Force and Moment Sensing Pushrim 352
Joint Kinetics and Kinematics for Three Speeds of Wheelchair Propulsion 355
Characterization of Upper Extremity Joint Kinetics during Wheelchair Propulsion 358
The Effects of Rear Wheel Camber on Physiological and Perceptual Responses During Simulated Wheelchair Exercise 361

SIG-10 Electrical Stimulation

Development of a FES System for C4 Tetraplegia 366
The Effects of Intramuscular Electrical Stimulation on the Temporal Gait Characteristics of a Child with Spastic Diplegia: A Case Study 369
Long Term Stability of Nerve Cuffs Implanted in the Cat Forelimb 372
An Eight-Channel Biphasic Stimulator for Functional Electrical Stimulation 375
Powering Sensors with an Implanted FES System 378
Comparison of Technology Match Between Two Types of Functional Electrical Stimulation Hand Grasp Systems 381
Control of the Hand Intrinsic Muscles by Functional Electrical Stimulation 384
Transfer Function Identification between Muscle Torque and Stimulus in Electrically Activated Knee Muscles 387
FNS Assisted Standing Pivot Transfers for Individuals with Incomplete Tetraplegia 390
Electrical Stimulation in the Management of Muscle Disuse or Temporary Muscle Denervation can be Effective and Comfortable 393
Electrically-Induced Contractions vs External Compression for Promoting Venous Return During Hip and Knee Surgery 396

SIG-11 Computer Applications

Adapting Speech Input Computing for Individuals with Speech Impairments 400
Grippy Mouthstick for Managing Floppy Disks and Compact Disks 403
Using an Extensive Abbreviation System to Make Augmentative Speech an Effective Reality 405
Computer-Animated Sequences as an Instructional Aid in Wheelchair Propulsion Mechanics 407
Providing AAC Device Access to the Macintosh 410
MCDC: The First Input PC Card 413
Interactive Computer Video: A Training Tool for Dynamic Prosthetic Alignment 416
The Bloorview Entertainment Plus: Multi-Model Access to Infrared Controlled Home Entertainment Devices, Lights, and Appliances 419
Single Switch Direct Manipulation 422
Virtual Interaction: An Interface for Individuals with Disabilities 425
A Computer Literacy Program in an Acute Rehabilitation Setting 428
Interface Design for Disabled Users: Eliciting User-Centered Constraints 431
Development of Orthocad - a CAD/CAM System for Lower Extremity Orthotics 434
Proposal for an ECU Standard Protocol 437
Assistive Computer Interface for Pen Input by Persons with Tremor 440
Sign PS: The Development of a Sign Language Printing System 443
Headpointing: The Latest and Greatest 446
Using AppleEvents to Increase Accessibility on the Macintosh 449
The Potential of Multimodal Interfaces for the Blind: An Exploratory Study 452
Metawidgets for Multimodal Applications 455
Integrating the Visual and Non-Visual Worlds: Developing Dual User Interfaces 458
Performance Differences Using Outspoken on the Macintosh Computer: Software for People with Blindness 461
Voice-Tactile Interaction Facilitating Blind User Access to an Adapted Multimedia Retrieval Application 464
Enhancing Non-Visual Interaction in a Graphical Environment through a Screen Reader Configuration System 467

SIG-12 Rural Rehabilitation

Mobilizing Assistive Technology Resources in Southwest Michigan 472
Community-Based and Outreach Rehabilitation: The Canadian Experience 475

SIG-13 Assistive Robotics and Mechatronics

The Development of an Interface Between the Spaceball 6DOF Isometric Joystick and the Manus Rehabilitation Robot 478
A Virtual Headstick Interface for a Master-Slave Rehabilitation Robot System 481
A Sensor-Based Manipulation Strategy for Applications in Rehabilitation Robotics 484
A Composite Proximity Sensor Array for Mobility Aids 487
A Simulated Environment of a Multimodal User Interface for a Robot 490
The Helping Hand Electro-Mechanical Arm 493
Instrumentation of the HANDY 1 for Oral-Motor Therapy 496
Development of an Evaluation Procedure for Wheelchair-Mounted Manipulator Arms 499
The Consumer Innovation Laboratory: An Exercise in Consumer Empowerment 502
Development of the QA Manipulator Arm 505
The VAHM Project (Autonomous Vehicle for Disabled Persons): First Results 508
A Household Mobile Docking Robot for the Assistance to the Disabled 511
A Mobile Robotic Unit for Clinical and Residential Care 514
Analysis and Design of an Arm Orthosis for Individuals with Muscular Dystrophy 517
An Evaluation of Residual Shoulder Function as an Input to a Variable-Impedance Assistive Robotic System 520

SIG-14 Job Accommodations

Modification of Office Chair Controls for Individuals with Limited Upper Extremity Movement 524
The Modification of Industrial Equipment to Enable a Person with a Severe Disability to Work 527
Custom Jobsite Accommodations: Two Case Studies 530
Jet Skiing for Fun and (Non)-Profit: Adaptations for Recreation and Small Business Development 532
A DIY, Low Cost Two Level Work Station 535
Job Accommodation Successes with Mature Injured Workers: Oregon Case Studies 538
Use of Job Accommodation by Employees Aging with a Disability 540
Vocational Robotics: Job Identification & Analysis 542
Wheelchairs in Controlled Environments 545
An Environmental Control System for a Severely Disabled Person Working at Home 548
Simplification of Essential Functions using Design for Assemble Techniques 551

SIG-15 Information Networking

A Comprehensive Sports and Recreation Program for Adults and Children with Disabilities 556
The RESNA Prototype Listserve - An Investigation into Electronic Communication 559

SIG-16 Gerontology

An Assistive Needlework Stand 564
Enabling Home Environments: Strategies for Aging in Place 567
The Development of a Primary Care-Based Assistive Technology Recycling Center 570

SIG-17 International Appropriate Technology

Ramping the Siberian Steppe: Wheelchair Marketing in Novosibirsk, Russia 574
The UCT Community-Based Rehabilitation Training and Resource Centre: A Primary Health Care Demonstration Project 577
An Innovative, Low Cost and Effective Method for B/K Sockets Prescription and Fabrication 579

SIG-18 Tech Act

Personal Assistance Services and Assistive Technology: Allies or Adversaries 584
North Carolina's Adaptive Equipment Loan Financing Program 587

SIG-19 Universal Access

BlissWrite and the BlissNet Resource Service: Resourcing Communicatively Impaired Individuals and Their Families using Computer Mediated Communications 592
Technical Requirements for Ramps: An Analysis of Current Accessibility Standards and Literature 594
Technical Requirements for Ramps: Human Subjects Testing 597
Mobile Homes as an Affordable Accessible Housing Option for Rural Individuals with Disabilities 600
Design and Development of New Toilet Fixtures to Meet the Needs of Disabled and Elderly People 603
Access to Banking Machines 606
Strategies for Improving Access to the Internet and World Wide Web 608
Adaptive Canoe Equipment Developed by Project PACE 611
Disabled Adventures - Developing and Promoting Access to Outdoor Recreation in South Africa 614

SIG-20 Cognitive Disabilities & Technology

Adults with Severe/Profound Disabilities--Issues and Trends in Technology Use in Day Programs and Residential Facilities 618
Architectural Barriers to Normalization: The Acoustic Environments of Group Homes 620
The Quarter Hour Watch, A Time Visualization Aid for Persons with Developmental Disabilities 623
Noun Cuing for Broca's Aphasics 626
Development of an Interface to Enhance Mobility for Persons with Neglect 629
A New Approach for Automatic Evaluation of Spatial Neglecting 632
Development of a Computer Software Program for Process-Based Assessment of Visual Perception in Persons with Neurological Disorders 635

PSG-04 Rehabilitation Engineers

Training Technicians for Careers in Rehabilitation Engineering Technology 640

Research Symposium

Developments Toward a Direct Brain Interface to Control Assistive Technologies

Development of an EEG-Based Brain-Computer interface (BCI) 645
Intracortical Recording of Brain Activity for Control of Limb Prostheses 650
Chronic, Multiple-Unit Recording of Neural Activity with Micromachined Silicon Microelectrodes 659
Command-Control Signals from the Neural Activity of Motor Cortical Cells: Joy-Stick Control 664
The Utah Intracortical Electrode Array as a Possible Motor Cortex Interface 667
Identification of Cortical Signal Patterns Related to Human Tongue Protrusion 670
Processing of Single-Trail, Movement-Related ERP's for Human-Machine Interface Applications 673
Electrocortical Differences Across Computational Paradigms 676
Toward a P300-Based Computer Interface 678
An EEG-Based Brain-Computer Interface (BCI) System Using Digital Signal Processing (DSP) Technology 681
Development of Direct Brain-Computer Communication in a Person with Amyotrophic Lateral Sclerosis 684
Improvement in EEG-Based Brain-Computer Communication by Use of Additional Recording Locations 687
Graz Brain-Computer Interface II: Studies for an EEG-Based Communication Device 690
Direct Brain Interface Utilizing Self-Regulation of Steady-State Visual Evoked Response (SSVER) 693
Control of Functional Electrical Stimulation with a Direct Brain Interface 696
Using the Electrooculogram as a Means for Computer Control 699
A Cursor Controller using Evoked Potentials and EOG 702

Whitaker Student Scientific Paper Competition

A New Approach to Suppressing Abnormal Tremor through Signal Equalization 707
Kinematic Analysis and Bandwidth Requirements of Sign Language 710
Identification of Cortical Signal Patterns Related to Human Tongue Protrusion (SEE in Research Symposium) 713
Simulations of User Performance with Word Prediction 714
Positional Dependence of the Recruitment Properties of Nerve Cuff Stimulating Electrodes 717

Student Design Competition

Design of Work Jigs to Assist the Disabled in Sheltered Workshops in the Production of Sample Display Chains 725
Tactile Sensing for Prosthetic Arms 728
Home Signaling System for the Deaf 731
Tool Modifications for a Dentist with a Cumulative Trauma Disorder 733
A Sandbagging Process that Accommodates the Mentally and Physically Disabled 736
An Open Interface Telephone for Custom Applications 739

Special Session - Current Trends in Wheelchair Propulsion Research

Wheelchair Propulsion Research - Past, Present and Future 743
Biomechanics of Wheelchair Propulsion: Relationship to Injury 746
Evaluation of Exercise Capacities of Wheelchair Users 749
Physical Capacity and Physical Strain in Persons with Quadriplegia 752
Manual Wheelchair Propulsion Center of Pressure 755

Author Index 759

SIG-01
Service Delivery and Public Policy

INFORMATION USE AND OUTCOMES FOR CLIENTS IN SEATING ASSESSMENT CLINICS

Gilbert D. Logan Royal Brisbane Hospital, Queensland, Australia.
David F. Radcliffe Mechanical Engineering Department, University of Queensland, Australia.

Abstract

The paper examines the utilization by a cross-discipline team of information that emerges during assessment of a disabled client for wheelchair seating and how this impacts on the quality of the equipment (design and manufacture) and the outcome for the client. The paper presents some results of an observational study of the manner in which information is gained, exchanged, lost by the team working in a teaching hospital based rehabilitation engineering centre. Paradoxically it was found that although the team processes seem inefficient the outcomes for the client were quite satisfactory.

Background

A cross-discipline team approach to the delivery of rehabilitation engineering (assistive technology) services continues to be widely practised. The size and composition of the team is changing as the medical model which advocated a medical practitioner "in charge of proceedings" devolves and services streamline personnel within budget stringencies. Now the focus of service delivery is the client and his / her right to seek out, request and control to a satisfactory conclusion, the services of professionals with expertise pertinent to their disability or difficulty.

The way the cross-discipline team deal with information has implications for the quality of service and the outcome for the client, particularly in providing customized devices[1]. Developing an understanding of effective and efficient information handling and use is important to ensure quality will be delivered to the client.

Tang[2] has described the use of video as a tool to identify how teams of designers accomplish their work. By this means he identified interactions in shared sketching work that had not previously been appreciated. As rehabilitation engineering client interactions involve significant visual input including mimicry and hand gestures, as well as oral input to present and manipulate information within the team, video taping offers a way of capturing all data for analysis.

Objective

The objectives of the research are: (1) Develop a process for handling transcript and video data to follow the information trail. (2) Ascertain if key factors exist in information handling by the team which strongly influence quality issues in the outcome for the client associated with design, manufacture, fitting and try-out of seating.

Method

Video tapes were made of a team composed of a professional rehabilitation engineer, orthotist, occupational therapist, physiotherapist, rehabilitation engineering technician. The tapes were made over a period of 12 months during which time team membership was consistent. The orthotist was new to the team and to customized seating work. Other members were experienced practitioners in their profession and had been associated with the Centre for over two years. The team was videotaped performing assessments of clients with severe physical disability and subsequent team-only discussions of assessment-derived information. The video camera, fitted with wide-angle lens was positioned to record activities of the team at work. The camera was moved to follow the team to various work areas.

Video tapes of four client assessments were reviewed and a transcript for each produced on word-processing software of what was said, who said it and at what time. The transcript was segmented into categories based on the physical components of equipment being prescribed including wheelchair, seat, backrest, headrest, footrests, tray, restraining straps. The elements in each category were examined to ascertain information conveyed that had a bearing on the design and manufacture of the wheelchair seating insert and the quality of the seating to meet the client's requirements. This information was tracked through the transcript to see how it was handled and to what use it was put.

The categorised information was checked against details of assessment and recommendation, design and manufacture in the client's file and against the finished product supplied to the client. Discrepancies in the use of information, interpretation of information and loss of the information were noted and referenced back to the transcript or video to see what may have caused this incident.

Results

1. Analytical information did not feature strongly in the assessment activity. Dimensions and numerical data made up 9% or less of team discussion.
2. Approximately 50% of team discussion points could be interpreted solely on the oral information presented. Approximately 32% of team discussion combined oral presentation with a visual activity, such as pointing, which required visual clues to aid correct interpretation of the data. The remaining 18% of team discussion points combined visual activity of such significance and detail that the oral component was uninterpretable without access to the associated visual component. The visual component of team communication was associated with approximately half of the team discourse.
3. Discussion had a social context with a high degree of non-verbal language – use of arms and hands to gesture, point, depict sizes, shapes, orientations and use of the body to mimic postures, movements of the client as statements about the specification of seating were made.
4. No sketching was observed in any video taped sessions although facilities were available for this.
5. Note-taking and recording of data such as measurements was rarely observed.
6. Client files, available throughout the team activity did not record the main points of team discussion or indicate how or why prescriptions were arrived at. File entries lacked clarity and detail and some prescription entries were inaccurate compared to the team resolution of discussion.
7. The starting point of team interaction and discussion with the client (after introductions and formalities) was always the most obvious physical problem with the client's seating. The team did not follow a consistent approach after the start in dealing with each case; examination progressed, regressed, circled and diverged seemingly according to input or interest of a team member.
8. Attention and discussion jumped between elements of the positioning and seating rapidly; sometimes the jump was logical, often it seemed random. Idea generation was frequent and spontaneous however 25% of ideas or suggestions were lost because they were not retained in team or individual memory or recorded for later discussion.
9. The team seemed to act with less determination and team discussion was less effusive if an advocate for the client (e.g. therapist or parent) was present and this person had definite ideas, demands and strong opinions.
10. Despite apparent deficiencies in the capturing of information inspection of the equipment manufactured for the clients appeared appropriate. Anecdotal opinion from parents and carers indicated most equipment had a high degree of acceptance.

Discussion

Rehabilitation engineering activity and the outcome for the client is heavily reliant on information input and use. The opportunity for a good outcome increases as relevant information is obtained and used effectively to devise reliable solutions to meet the client's requirements.

The use of a cross-discipline team to gather relevant information and interpret it takes advantage of a broad spectrum of knowledge, skills and experience of team members drawn from life sciences and physical sciences. As team members have roles in the process they have individual information needs and are likely to have preference for how information is presented. Rehabilitation engineering data used for developing and designing solutions to client-presented problems has oral and strong visual content[3]. In this analysis of four team-client interactions, each lasting over 60 minutes, 50% of communication of data required team members to see the associated visual content to understand and accurately interpret what was being said. As visual memory for detail is generally poor, it is likely a deal of this data is lost, particularly if the speed of oral/visual presentation is fast, erratic and disordered.

The analysis demonstrates the need for a team member to be allocated a specific role of "data collector" to keep written records and encourage use of tools such as the white board to sketch concepts for all to see and comment on.

While lack of controls over the client assessment and team discussions processes provides for unshackled thought and expression, there is evidence in the non-progressional, random and flip-flop discussion behaviours to recommend teams work to an activity list or prompt sheet to elicit responsiveness and dedication to task. It is important that controls do not dampen or discourage spontaneity and serendipity which are important for creativity and idea generation.

Conclusion

The use of a cross-discipline team in a rehabilitation engineering ensures client data is solicited from

BEST COPY AVAILABLE

complementary professional perspectives. The work of the team is characterised by the extensive use of non-verbal communication which is not recorded in any way. The process of arriving at a prescription (or design) is not a systematic one, rather it is an unstructured series of interactions and exchanges. Paradoxically however, the seating systems designed by the team using these methods appear to satisfy client needs. Unravelling this paradox will enable us to find if the delivery of rehabilitation engineering services can be made more efficient and effective in producing quality outcomes for clients.

References

1. Logan G.D., Radcliffe D.F., Considering Quality in a Cross-Discipline Rehabilitation Engineering Service, RESNA '94, pp37-39.

2. Tang J.C., Leifer L.J., An Observational Method for Studying Group Design Activity, Res Eng Des 1991, 2:209-219.

3. Radcliffe D.F., Slattery P., Emergence, Learning and Interaction in a Cross-Discipline Design Environment, DE Vol 42, Design Theory and Methodology, ASME 1992, pp 123-130.

Acknowledgments

The assistance of Brisbane North Regional Health Authority in providing facilities for this work is acknowledged.

Author

Gilbert Logan
Royal Brisbane Hospital
RBH Post Office, Queensland 4029
Australia.
phone +61 7 2537412
fax +61 7 2531389
Internet address: logan@sun.mech.uq.oz.au

DEVELOPMENT OF A BED OVERLAY TO CONTROL EXTENSOR TONE, IMPROVE RESPIRATION, AND REDUCE MATTRESS INTERFACE PRESSURES

Jon Schuch, M.E., Assistant Professor of Physical Medicine and Rehabilitation, University of Virginia
John P. Pelegano, M.D., Assistant Professor of Pediatrics, University of Virginia
Charlottesville, VA

ABSTRACT:

This paper describes a clinical case in which a bed overlay was successfully developed for a 13 year-old girl with spastic cerebral palsy and severe extensor tone. The girl presents a history of sleep-related problems, the most recent of which were associated with severe opisthotonos, gastroesophageal reflux, and resultant laryngeal ulceration and erythema. Pathology resulted in acute, severe airway obstruction, with cyanosis. In order to help diminish these problems, a bed overlay was developed to control the girl's extensor tone, improve her respiration, and reduce the risk of gastroesophageal reflux and decubitus ulcer development. While the bed overlay was developed specifically for this girl, it can be easily replicated for others with similar needs.

BACKGROUND:

Alison is a delightful 13 year-old female with a primary diagnosis of spastic quadriparetic cerebral palsy. Throughout her life, she has exhibited severe extensor tone resulting in dynamic hyperextension in the cervical, lumbar, and pelvic regions. While she possesses adequate hip and knee range of motion for upright sitting, she possesses marked fixed lumbar lordosis and anterior pelvic tilt. If unsupported, she fixes in an opisthotonic posture, with back arched and neck hyperextended, as shown in Figure 1.

Alison's medical record documents a long history of sleep-related problems. Throughout her life, she has been a light sleeper, waking frequently through the night. A one-hour sleep pattern and irritability at night was documented in 1991. Separate trials of Valium and Klonopin did little to improve Alison's sleep. A variety of alternative positioning devices and strategies were also tried, but did not help to reduce Alison's distress.

The past year has seen an exacerbation of Alison's sleep-related problems. She would sleep in 15 minute intervals, exhibit severe truncal hyperextension and opisthotonos, and appear to be in significant pain. Again, drug therapy and positioning strategies were unsuccessful. These problems reached a critical stage when in September of 1994, Alison began to have episodes of acute respiratory distress, requiring resuscitation and other emergency treatments. At this point, Alison was admitted to the Kluge Children's Rehabilitation Center at the University of Virginia for a complete medical evaluation. Laryngoscopy revealed significant and dynamic compression of the lower trachea secondary to its compression against the spine with spastic hyperextension, as well as ulcerated arytenoids and erythema in the major airways thought to be secondary to gastroesophageal reflux and associated aspiration. When placed in a horizontal sleeping position, the gastroesophageal reflux would worsen, causing pain, agitation, and hyperextension. Her airway would partially occlude, resulting in stridor and respiratory distress.

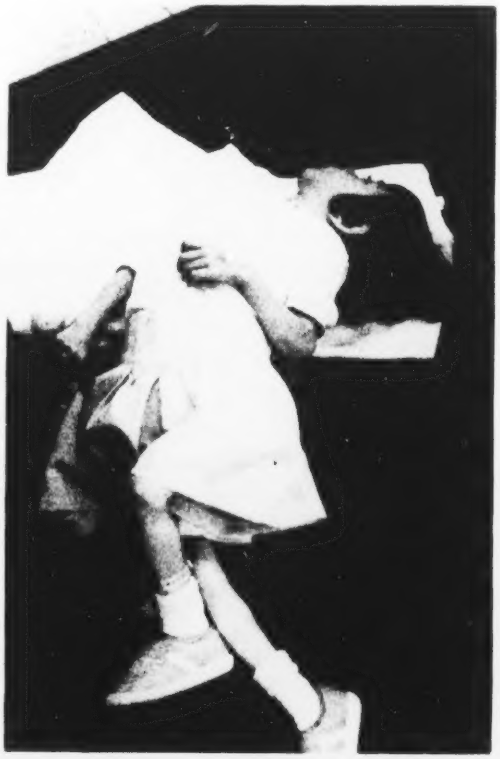


Figure 1. Opisthotonic Posture Exhibited in 1986

24

To correct these problems, tracheostomy placement, nissen fundoplication, and G-tube placement procedures were performed. The tone reducing medication, Baclofen, was introduced. It was also felt that Alison needed a positioning device that would comfortably support her in a side-lying, head elevated position at night. This device would serve as an alternative to her wheelchair seating and positioning system and, more importantly, would maintain her in a position that would facilitate gastric emptying and would minimize gastro-esophageal reflux and dynamic airway compression.

OBJECTIVE:

The objective was to implement a positioning device that would comfortably support Alison in a side-lying position, which is her preferred position. The device should reduce Alison's hyperextension and opisthotonos, improve her respiration, and allow for eight hours of continuous usage without risk of decubitus ulcer development.

Additional design parameters were identified via consultation between physician, nurse, respiratory therapist, physical therapist, rehabilitation engineer, and Alison's parents. First, the device should allow Alison to lie on either her right or her left side without manipulation or reversal of supports, straps, or other device componetry. Second, the positioning device should be angle adjustable to allow elevation of Alison's head and torso relative to her pelvis and lower extremities for enhanced respiration. Third, the device should incorporate pressure-relieving technology to reduce pressures, particularly at the greater trochanter. Fourth, it should fit on top of Alison's bed at home, thus functioning as a bed overlay positioning device.

METHOD:

Because of the success of a side-lying positioning device made for Alison in 1986 (Figure 2) and similar successes reported by Cosme (1), it was decided to develop a positioning device for Alison using a carved foam technique. For a person with basically two-dimensional contours like Alison, this technique works quite well and is significantly less labor intensive than the foam-in-place technique reported by Harmala, et al (2). First, Alison was held in sidelying in her most flexed position with two clinicians applying the external forces needed to achieve and maintain this posture. An outline of this posture was made by shaping a thin-gage wire to the posterior of Alison's body. This contour was then transferred to paper for a permanent pattern. The pattern was traced on two pieces of 70 I.L.D. polyurethane foam 4' long X 1' wide X 8" thick and the transferred contour was cut with a band saw. Two pieces were used to yield a left and a right side-lying posterior support.

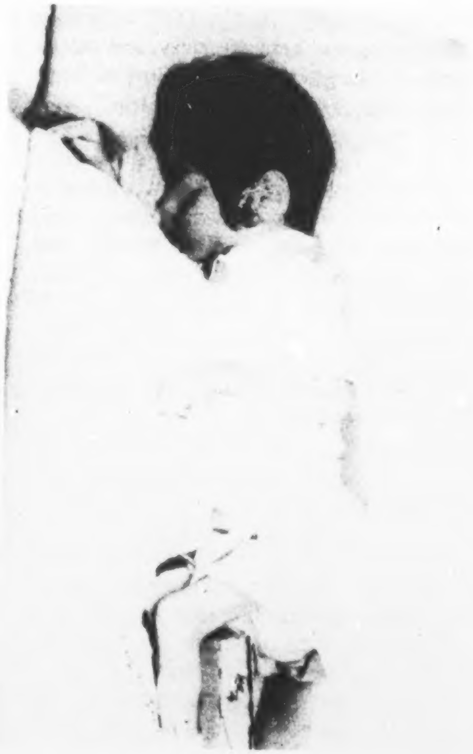


Figure 2. Alison in Sidelyer Developed in 1986

A 4" thick Geo-Mat foam mattress overlay, made by Span America, was used as the base foam for the bed overlay because it satisfactorily distributes interface pressures. The Geo-Mat was cut to a 4' length and 35" width to accommodate Alison's 3' body length and to match the width of her bed at home. The shape of the posterior supports were then cut out of the left and right sides of the Geo-Mat in order to mate the Geo-Mat and the posterior supports.

Angle adjustability of the bed overlay was achieved by attaching two pieces of 4' X 35" X 1/2" plywood together at the "foot" of the bed overlay by means of Pin Dot Dial Links and Wood Adapters. The Dial Links are bolted to the Wood

Adapters, which are in turn attached to the plywood with 1/4-20 bolts and T-nuts. This design yields infinite angle adjustability from horizontal to beyond a 45 degree incline. The mated Geo-Mat and two posterior supports simply lay on the top piece of plywood, and are held in place in part by being squeezed between the Pin Dot hardware.

Anterior support is achieved by means of a 4" wide elastic strap that encircles Alison and the foam unit. The strap is positioned at the apex of Alison's anterior or ventral curve, and provides the anterior to posterior force needed to hold Alison in the posterior support and, thus, reduce her hyperextension. Because the bed overlay is designed for left and right sidelying without requiring reversal of componetry, two straps are used, one for each posterior support. The bed overlay is shown in Figure 3.

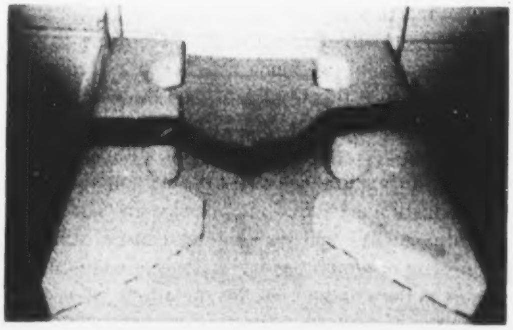


Figure 3. Bed Overlay

RESULTS:

At the time of this writing (Jan. 1995), Alison is sleeping 8 or more hours per night. She sleeps peacefully, without distress, and without the severe hyperextension exhibited in the past. Her parents report a more relaxed breathing pattern, reduced congestion, and improved circulation. To date, Alison has shown no risk of decubitus ulcer development, suggesting that the Geo-Mat is performing as intended.

Alison's parents report that the bed overlay is easy to use and that it is easy to position Alison within the device as intended. They feel Alison is comfortable and content when in the bed overlay, and that she likes the support it provides. Figure 4 shows Alison in her bed overlay positioning device.

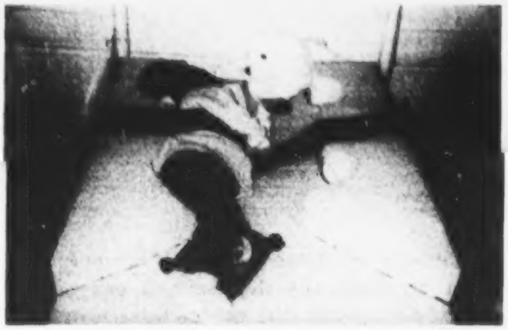


Figure 4. Alison Positioned in the Bed Overlay

DISCUSSION:

To be sure, the surgical intervention and the introduction of Baclofen are significant factors in Alison's return to a normal sleep pattern. But the implementation of the bed overlay, which successfully controls Alison's hyperextension and opisthotonos, improves her respiration, and reduces the risk of gastroesophageal reflux, dynamic airway compression and decubitus ulcer development, cannot be overlooked. The device is an effective adjunct to the medical management of these problems and is a practical bed overlay positioning device that is easily replicated for others who have similar needs.

REFERENCES:

1. Cosme JG. Three Postural Positioning Devices. In: *Proceedings of the Second International Conference On Rehabilitation Engineering*. Ottowa, Canada: 1984; 469-470.

2. Harmala K, Gonzalez A, Musselman V, Crawford D, Cielinski S. Custom Molded Supine, Side Lying, and Prone Positioners. In *Proceedings of the RESNA International '92 Conference*. Toronto, Canada: 1992; 522-523.

Jon Schuch, M.E., Assistant Professor
Department of Physical Medicine & Rehabilitation
University of Virginia Health Sciences Center
Box 35-BRH
Charlottesville, Virginia 22908
(804) 982-3845
e-mail jzs@virginia.edu

THE ALBERTA EXPERIENCE IN RECYCLING DURABLE MEDICAL EQUIPMENT

Ian Searle and Deb Maerz
Alberta Health, AADL Program
10030 - 107 Street
Edmonton AB Canada T5J 3E4

ABSTRACT

The provision of Durable Medical Equipment to disabled or chronically ill clients is one of the important components that enable clients to remain independent in the community. The ability to provide these benefits in a cost-effective manner (ie maximizing tax dollars while still meeting each persons unique but basic needs) is achieved by utilizing a "Formal Recycle Program" as well as a "Community Recycle Program".

BACKGROUND

The AADL Program is a Government funded Program within Alberta Health. The mission of the AADL Program is to provide basic equipment, supplies and services to disabled and/or chronically or terminally ill residents of Alberta. These benefits are supplied to enable clients to live more independently in the community.

All clients are subject to cost-sharing unless they are unable to do so (eg clients on Social Assistance or receiving the Assured Income for Severely Handicapped or Income tested). The AADL Program contributes 75% toward the cost of benefit(s) and the client is responsible for 25%. The amount that a client or their immediate family will cost share is limited to a maximum of $500 each benefit year.

The Program supplies a number of different benefits such as:

- light rehab equipment
- positioning aids (specialized seating)
- compression garments and dressing supplies
- custom made footwear, prosthetics and orthotics
- electro-larynx and hearing aids*
- manual hospital beds
- wheelchair accessories
- power and manual wheelchairs
- respiratory benefits

The Program deals with two types of recycling:

- formal (costs involved and tracked by computer)
- community (no cost)

METHOD

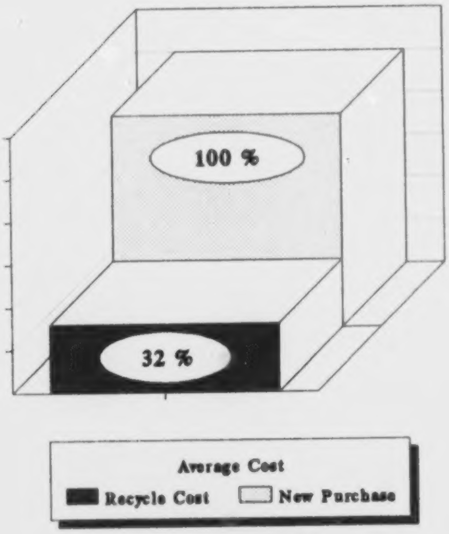
Large equipment (wheelchairs, commodes, patient lifters etc) that costs more that $250.00 remain the property of the Alberta Government once purchased. These benefits are provided on extended loan to eligible clients. When a client no longer needs the equipment, it is returned to a contracted vendor who informs the Program that the equipment has been returned. The method of reporting is by the submission of a standardized Work Order which contains an estimate to refurbish the equipment, the serial number and any information available of the previous user (name, personal health number etc). This information is verified on the computer and the information is entered into the system. The computer automatically updates the inventory sub-system, showing at which vendor the equipment is stored as well as the estimate. At the same time, the computer updates records to show the equipment is no longer on loan to the previous user. The vendor is then paid an administrative fee and a shipping fee if applicable.

An order for equipment is placed with the Program by a health professional (authorizer). The Program tries to source the equipment from the 'Recycle Pool' first.
The equipment is refurbished to an acceptable condition by the vendor and then it is delivered to the client. The vendor is paid for new parts, labour, freight, storage, and an administration fee.

If no match is found, the Program will purchase new equipment.

It costs approximately 32% of new purchase to formally recycle the equipment. This cost includes labour, parts, shipping, storage and an administration fee.

RECYCLE PROGRAM
NEW PURCHASE VS RECYCLE COST



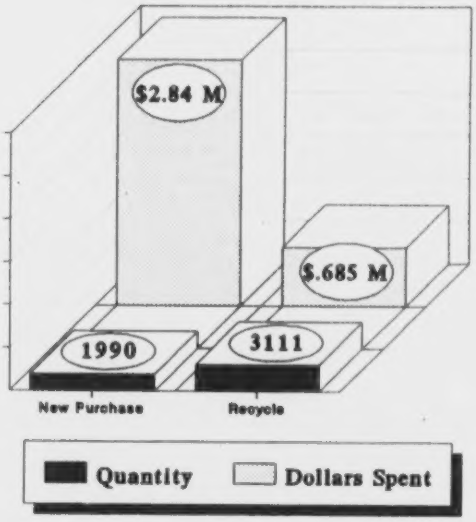
BASED ON 1994 STATISTICS

Internal Transfers are a no cost variation on recycling and are usually performed within facility settings. When a client no longer requires the equipment, the authorizer is able to assign that piece of equipment to another client as long as it is suitable and does not require a change in configuration. A form is sent notifying the Program that the equipment has been transferred, providing the new client information.

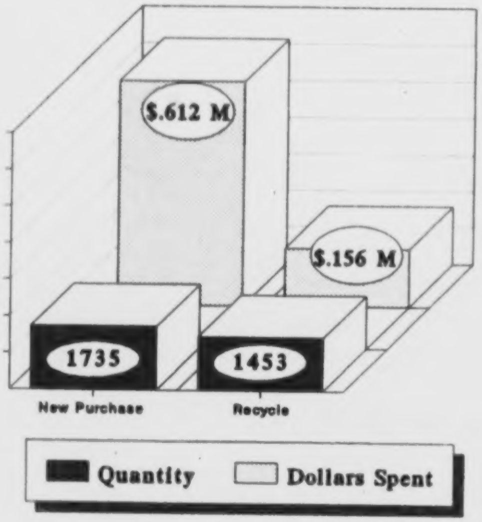
RESULTS

The Alberta Government saves approximately **4 Million dollars** each year by recycling durable medical equipment.

RECYCLE PROGRAM
WHEELCHAIRS



RECYCLE PROGRAM
LARGE EQUIPMENT



RECYCLING MEDICAL EQUIPMENT

COMMUNITY RECYCLE

Once this equipment is purchased, it becomes the property of the client. When no longer needed, the equipment can be returned to the local health unit or the Red Cross. If the equipment is considered safe and usable, it will be made available to another eligible client. This is a no cost transaction and there is no formal paperwork process.

ACKNOWLEDGMENTS

Information provided by the Alberta Aids to Daily Living Program.

Patrick McCready and Neil Prather for providing valuable contributions in compiling data and statistics.

Ian Searle
Project Manager, B.E.S.S.I.
AADL Program
10030 107 Street
Edmonton AB T5J 3E4
ph. (403) 427-2631 ext 256
fax (403) 422-0968

DEVELOPMENT OF A CAR SAFETY RESTRAINT FOR CHILDREN WHO ESCAPE COMMERCIAL SYSTEMS

Nanette S. Hughlett, M.E. and Jon Schuch, M.E.
University of Virginia, Rehabilitation Engineering Services
Charlottesville, VA

ABSTRACT

Children are required by law to be safely restrained while riding in a vehicle, whether by seat belt or car seat. Our rehabilitation team was presented with two cases where children would regularly disengage themselves from their safety restraint. Coupled with the risk of no restraint, these children exhibited violent behavior causing harm to themselves and others. A thorough search of the commercial market yielded no commercial equipment that would meet our needs, thus, we designed a car restraint system by combining two commercial, crash tested devices and incorporating a custom designed and fabricated pelvic belt. By integrating the Columbia car seat, the EZ-On vest, and a custom pelvic belt, these children were able to be safely secured while in a vehicle.

BACKGROUND

Our rehabilitation team was consulted to work with two children who could not be securely restrained in vehicles and were causing unsafe distractions during travel. The first case involved a 4 year-old boy with a diagnosis of pervasive developmental delay or autism. As a result of his disability, this child became agitated when placed in a vehicle. As his mother or grandmother put him into his car seat, he struggled with her, kicking, hitting, and biting her. Once in his car seat, he regularly disengaged himself and attempted to strangle the driver, cover the driver's eyes, throw objects, open the car door, climb out the window, and injure himself. The second case involved a 6 year old boy who has either a seizure disorder or "uncontrollable fits of rage", as defined by his primary care physician. When one of these "fits" occurred in the car, the boy often escaped from his safety restraint and caused a disruption. These disruptions included throwing objects, opening the car door, or crawling out the window. This boy would frequently disengage himself from his safety restraint when on his school bus and open the bus door while it was moving. As a result of both childrens' actions, the families have been stopped by the police and even ticketed. Each family reports that they are unable to travel with their child unless two adults are present.

OBJECTIVE

To provide a safety restraint system for use in a vehicle to hold the child securely and safely during travel. The safety restraint must be simple enough to be managed by one adult, must fit any style of vehicle, must securely restrain the child without fail, and must not hinder rescue personnel from extracting the child from the vehicle in an emergency or accident.

METHOD

Each child was evaluated in all types of commercial car seats and safety vests. Within minutes, the children were able to undo buckles and move straps to free themselves. It was determined that each child could unlatch any push button latch and could manipulate movable straps within their reach. An extensive product search was performed to ensure that a suitable commercial device was not overlooked. Since both of these children weigh more than 35 pounds, a restraint that has been crash tested for larger children was needed. No commercial device was found that could meet the childrens' needs. Consequently, a custom car seat was designed.

The first concern in the design and fabrication of the custom car seat was safety. Besides restraining the child, the car seat needed to be easily used by the family and rescue personnel, in daily use and in the event of an emergency. Before pursuing the project, our Department of Risk Management was consulted for procedural guidance. In addition, rescue squads throughout the state were contacted to learn their technique for removing children from cars and car seats in emergency situations. The rescue squads reported that they remove the child while seated in the car seat as a first resort and that they saw no problems with a custom car seat, as long as it was secured in the car in the regular fashion. Our engineers then consulted leading engineers in the automobile safety industry and engineers specializing in vehicular transportation for persons with disabilities. Using their recommendations, a car seat was designed that incorporated two items which had both met national crash test standards with a custom pelvic belt. The Columbia Car Seat and the EZ-On Safety Vest were secured using the custom pelvic belt. The custom belt was necessary to allow easy access to the seat without push button or squeeze type latches.

Fabrication took place by removing the Columbia Car Seat's harness and cutting a small slot (1/2" by 2") through the back of the car seat shell. The EZ-On vest was then attached to the Columbia shell using the portable seat mount. This mount wrapped around the Columbia car seat, as it would a bus seat, with the lower tab sliding through the slit. This mount then interfaced with the child's EZ-On vest. Since the children could undo regular seat belt push buttons, a custom belt was fabricated using a snap hook which could not be unbuckled in the front when the belt was tightened from behind. All clasps and buckles for tightening were located behind the car seat for use by the individual securing the child. This kept them out of the reach of the child, preventing the child from detaching them when the vehicle was in motion. These items, when incorporated into one system, provide the restraint needed for each child. The car seat shell, vest and pelvic belt is shown in Figure 1. In the design, no modification was made to the securing method of the Columbia shell in the car. Once fabricated, significant time was spent training the family in the proper usage and fitting of the device in the car. The final car seat is shown in Figure 2.

RESULTS

After being secured in the car seat, each child remained restrained. The strapping on the EZ-On vest was not movable and the clips and buckles were out of the child's reach. Each parent was able to get their child in and out of the car seat with little effort. Since no change was made to the mount of the car seat, the seat fit easily into each car and could be used in multiple vehicles. Each car seat has been used for over six months with positive results. The families report that their child is unable to disengage themselves from the seat on their own. They have found the seat to be easy to use by a single individual. One mother reports that, "It is great to get into the car and feel safe."

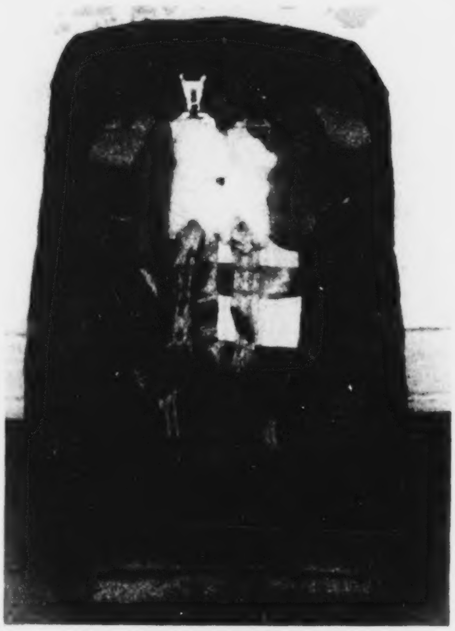


Figure 1 - Columbia Shell, EZ-On Vest and Custom Pelvic Belt

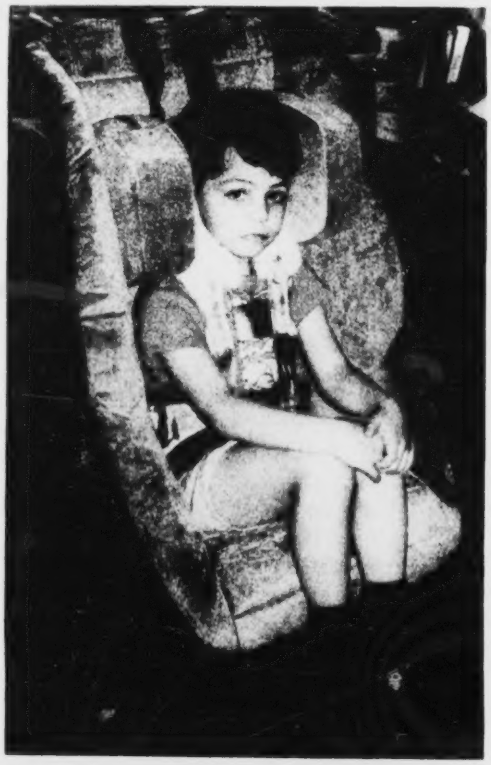


Figure 2 - Custom Car Seat with Child

DISCUSSION

It is never one's choice to alter a crash tested device. Yet, when the commercial car seats and vests fail to meet the safety needs of a child and family, changes must be made. In these two cases, all commercially, crash tested car restraints were unable to hold the child effectively. This lack of restraint led the children to cause harm to themselves or others in the car. It was felt that without making a change to these car seats, the children were more likely to cause a car accident and thus harm others. By incorporating two commercial, crash tested devices into one system and minimally changing each device, these children were able to be safely and effectively restrained in a vehicle. Since no change was made in the mounting of the seat within the vehicle, rescue personnel will be able to remove the safety seat if necessary. After six months of usage, both families report that the car seats are effectively restraining their children.

Nanette S. Hughlett
Rehabilitation Engineering Services
Box 35-BRH
Charlottesville, VA 22908
(804) 982-3845
e-mail njs8j@virginia.edu

HUMAN DIVERSITY AND ASSISTIVE TECHNOLOGY SERVICE PROVISION

LUCY TRIVELLI VITALITI, PH.D.
RESNA
Arlington, VA U.S.A.

ABSTRACT

Human diversity includes geography, age, disability, race, ethnicity, and culture, as well as gender and socio-economic status. All of these impact a person's acceptance of and access to assistive technology. At the RESNA Forum on Human Diversity held in Washington, DC in July 1994, papers were presented addressing several high priority diversity and assistive technology topics, namely outreach and strategies for assistive technology service delivery to persons with disabilities in rural areas, Native Americans, Southeast Asians, and the elderly. This poster presentation will present the training program that was developed from papers presented at the Forum.

BACKGROUND

Dramatic changes in our nation's demographics, reflecting a rapid growth of individuals from diverse backgrounds, warrants the development of skills necessary to effectively serve people from other cultures. This presentation will pull from the Curriculum on Human Diversity which was developed from papers presented at the Forum on Human Diversity held in Washington, DC. The curriculum was developed to train human service personnel on historical, cultural and social aspects of diverse populations, in particular the elderly, those living in rural areas, Southeast Asians, and Native Americans. The curriculum also provides information on how "traditional" U.S. human service systems may not be responsive to individuals from diverse cultures. Presented are functional, replicable service delivery strategies that are culturally responsive.

OBJECTIVE

Dissemination of this type of information to assistive technology providers will be a first step toward inclusive and appropriate services for all persons with disabilities.

STATEMENT OF THE PROBLEM

Data from 1990 census indicate that between 1980 and 1990, the rate of population growth of white Americans was approximately 6%, African Americans was 13.2%, Hispanics 53%, Vietnamese 135%, Native American 37% (U.S. Dept. of Commerce, Bureau of the Census, Summary Tape File 1a, 1991). Minorities experience disability at a proportionately higher rate and may have increased potential use of assistive technology. There are additional factors that influence assistive technology service delivery and service utilization that include geography, topography, economy of the local region, history and traditions of a region, all of which comprise the culture of a region or group.

APPROACH

Authors' presentations and reactor statements made at the Forum on Human Diversity were developed into topic modules in a curriculum for training on diversity and service provision. Presented at the RESNA conference will be a synopsis of each of these topic modules, an outline of the information contained in the training materials, and actual exhibit of the curriculum.

DISCUSSION

There are many aspects to assistive technology service provision that need to be considered in addition to evaluation, measurement, prescription. Other facets of a person also need to be considered, such as their culture, race, age, gender, history, ethnicity, demographic effects, and geographic location. All of these facets have an effect to some degree on the acceptance and use of technology, successful integration of technology in daily life, and effect on desired long-range goals. For example, outreach and assistive technology service provision mechanisms for persons with disabilities residing in rural communities requires creativity on the part of the service provider and utilization of all existing resources. The rural rehabilitation professional must demonstrate additional competencies in flexibility and cultural diversity. Rural consumers have specialized needs such as accessible transportation, available health care, barrier free places of shopping, and access to peers. In addition, influences from the culture of that rural region may exist that influence a consumer's acceptance of assistance, use of technology, or involvement of service personnel in their lives. These needs must be considered when coordinating services between the rehabilitation/assistive technology professional and the consumer.

REFERENCES

Curriculum on Human Diversity, Developed Modules from the Forum on Human Diversity (1995). Arlington, VA: RESNA.

U.S. Dept. of Commerce, Bureau of the Census, Summary Tape File 1a, 1991.

ACKNOWLEDGEMENTS

The Forum on Human Diversity and the subsequently produced Forum Proceedings and Curriculum, were components of Project Reaching Out, a project funded by the U.S. Department of Education, National Institute for Disability and Rehabilitation Research under Public Law 100-407, The Technology-Related Assistance for Individuals with Disabilities Act of 1990.

Lucy Trivelli Vitaliti, Ph.D.
Project Director
RESNA
1700 North Moore Streeet, Suite 1540
Arlington, VA 22209 U.S.A.
703-524-6686, ext. 310

A STUDY OF THE PROXIMAL STABILIZATION PROGRAM: ITS EFFECT ON GAIT AND RANGE OF MOTION

Damador G. Kamath, Sandy Armitage, Richard D. Beauchamp,
Nalini Bhaskaranand, Madhu Manikanta, Radha Prabhu
Proximal Stabilization Centre, Surrey BC Canada V3S 3C1

ABSTRACT

Proximal Stabilization Therapy (PST) was developed to support the abdominal muscles dynamically in a program of progressively training children with CP in functional skills. After receiving PST for three to nine weeks, the ten children in this study showed significantly reduced spasticity, measured with ROM scores and indirectly through gait analysis. All subjects exhibited better antigravity security, reduced spasticity, and increased ROM and independence of movement at the end of the study. One child learned to walk independently, and two others learned to walk with assistance. The PST system appears to alter the natural history of the child, including the development of contractures and the need for surgery, seating systems and therapy.

BACKGROUND

Stabilizing the body proximally is fundamental to developing skilled movements in the distal musculature, postural control, and balance and coordination. Studies of proximally stabilizing children with CP noted that adaptive seating provides advantages for children with CP (2, 3, 4), including faster arm movement (5, 6), greater speech intelligibility and reduced hypertonicity (1).

Most studies have examined stabilizing the child in a static, seated position. Proximal Stabilization Therapy (PST) stabilizes the child using a dynamic support in a program of progressively training in functional skills. Clinical experience suggests that with PST, contractures were reversed or arrested; the children exhibited rapidly reduced spasticity and improved posture and balance; that they learned to walk without help, and to reach and grasp more effectively.

This study sought to determine whether PST effects functioning and spasticity, as indicated by joint range of motion (ROM) and footprint analysis.

METHOD

Nine quadriplegics and one diaplegic between fifteen months and six years old were diagnosed and referred by therapists at K.M.C. Hospital, Manipal, India. All had received current therapy, none was ambulatory, had received surgery or used bracing. Children were selected by age, parental commitment and retardation level; no child that met the minimum criteria was eliminated. PST is most effective with hemiplegics when introduced between 12 and 24 months of age; for diaplegics and quadriplegics, between 15 and 36 months of age. One severely retarded child was included for comparison.

Randomness was limited by availability and by being referred to a hospital. We believe these limits to randomness are reasonable: parents deliver PST; it's an educational program; being referred to a hospital is normal to the population who will use PST in the future. We did not create a control group because of finite resources, limited subject availability and variability among CP children.

Eight children were selected. We designed the study with three pretests at two-week intervals. Five subjects were withdrawn by the parents before the PST therapist arrived in India. Thus, we only have pretest scores for subjects 1, 4, and 7; none showed change of status during the pretest period.

During the first week of PST, parents were trained in using the equipment, goal setting and motivating their children to reach these goals. When the children felt at ease with the equipment, the parents provided two-hour sessions, twice daily. Parents then provided PST at home and returned to the hospital weekly for testing and help.

Separate therapists tested the subjects with Bayley's Scales of Infant Development, with a structured video analysis of functionality, with a paediograph for gait analysis, with range of motion (ROM) measures, with a limb-load monitor to measure weight bearing on each foot, for grasp pressure, and for hand and feet temperature. The traditional paediograph was modified because of the expense of transporting materials from North America. Subjects walked along a specially designed tray, leaving footprints on a footprints on a transparent plastic graph matrix. Therapists then copied the footprints onto a paediograph form for analysis. The analysis of the paediograph was also modified to specifically address changes in spasticity, as indicated on the graphs below. Heel-toe gait was defined as a complete footprint, even with metatarsal bars.

The first two data points and last two points were each averaged for each child to obtain scores that were less affected by temporary variations in performance. Each first and last average score was converted into a *z score*, used to measure change that is unaffected by the huge individual differences observed with CP and with young children. The differences between scores at the beginning and end of the study were compared with the *Student's t test*.

RESULTS

Subject #1 (boy, 3¼ yrs.): Initially, unable to sit or roll onto left side; needed help to raise head; could reach with one hand. After PST, could sit in ambulator with head up for 20 minutes, reach for toys with both hands, bear weight standing a few seconds with help. Also gained bowel control.

Subject #2 (boy, 5½ yrs.): Initially, musculature was flaccid; stayed in a fetal position; could not sit up, crawl, bottom scoot, or reach for toys. After three-weeks of PST, toilet trained, could sit on a bench for 15 minutes, could bear weight with help balancing, started reaching for toys and playing.

Subject #3 (girl, 2.1 yrs.): Initially, rigid, exhibited constant involuntary movements; couldn't sit, hold head up or turn it, use her hands. After three weeks of PST, could sit cross-legged, hold head up, turn it, and grasp. All involuntary movements stopped.

Subject #4 (boy, 2¾ yrs) Initially, could only stand on toes, feet twisted in an inverted position; needed support to sit and stand. After five weeks of PST, could stand independently in the ambulator, propel it forwards and backwards without tensing or inverting feet. His reach was more accurate.

Subject #5 (boy, 5½ yrs.) Initially, could sit briefly when propped in a corner, could stand or walk with extensive help, could not flex knees or lift legs while walking, supported himself on toes; seldom reached for toys. After five weeks of PST, could bend both knees in walking with minimal support from behind, shift weight and stand independently in the ambulator, use both hands to reach, pick up toys more accurately and with less spasticity.

Subject #6 (girl, 6 yrs.) Initially, could only pick up objects with toes, usually sat against a wall for security, could not stand; only moved by bottom scooting. After five weeks of PST, could stand alone, walk six steps without help, pick up objects with right hand, and transfer them to the left hand.

Subject #7 (boy, 2¼ yrs.) Initially, could stand alone for a moment, moved by bottom scooting, walk only with a held hand, used two-word phrases to communicate. After seven weeks of PST, could run, kick a ball, pick it up from a standing position, and join full sentences together in conversation.

Subject #8 (girl, 4 yrs., severely retarded) Initially, could sit and not ambulate at all. After PST, could stand and sit alone in the ambulator, and move it forwards and backwards.

Subject #9 (girl, 1½ yrs.) Initially, couldn't stand or bear weight on feet. After five weeks of PST, could stand alone without ambulator for 15 minutes, walk with minimal help from behind, get up from the floor using only one hand, move from chair to chair.

Subject #10 (girl, 1½ yrs.) Initially, could sit, but not stand even assisted. After four weeks of PST, could get up from the floor using one hand, stand alone at a table, and take steps with help.

Statistically, the *Student's t test* to analyze *z scores* indicates the significance of these improbable directional trends. *Student's t test* to analyze *z scores* is only meaningful to the degree that other therapies do not achieve the same directional trends.

Figures 1 and 2 graph the increasing percentage of full foot prints over total foot prints on the left and right sides. The *Student t test* indicates statistical significance for the differences for both the average raw scores and the *z score* measure of change ($p \leq 0.005$ for both scores). Partial footprints are usually caused by spasticity in the heel cords.

FIGURE 1: Percentage of left full foot prints.

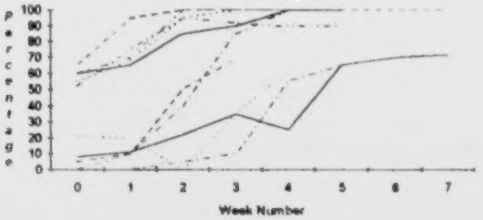


FIGURE 2: Percentage of right full foot prints.

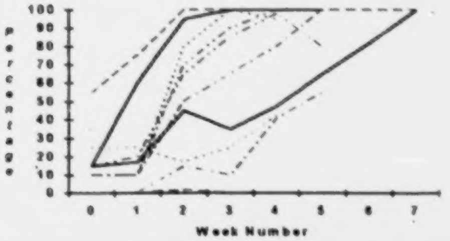
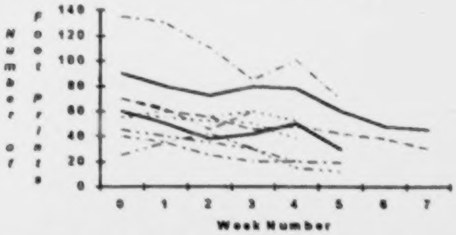


Figure 3 graphs a decreased number of foot prints during the study, suggesting improved range of knee extension and decreased hamstring spasticity. Using the *Student t test*, the change was found to be not significant for the average raw scores, but statistically significant for the *z score* ($p \leq 0.005$).

FIGURE 3: Total number of foot prints.



Figures 4 and 5 graph the increasing active hip flexion-extension range for both feet during the study. The *Student t test* found these changes to be statistically significant for both average raw scores and *z scores* ($p \leq 0.005$ for all four scores).

FIGURE 4: Active range between extreme flexion and extreme extension of left hip.

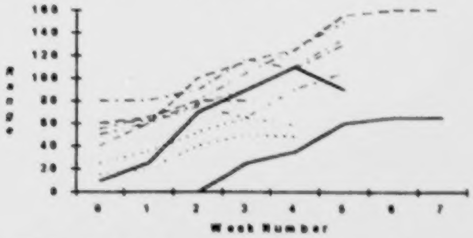
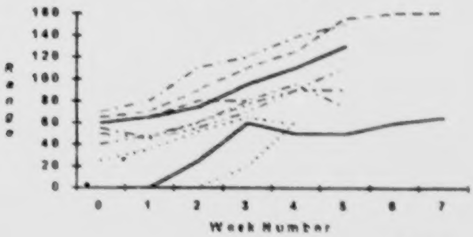


FIGURE 5: Active range between extreme flexion and extreme extension of right hip.



DISCUSSION

PST has been provided by our parents' association for a decade. Our experience suggests that PST provides the benefits of adaptive seating without restricting breathing, walking and other movements. The health and functioning level of the whole body is enhanced. (Additional measures of improvement are shown on a video about the Manipal study.)

Our system relies on parents to provide the therapy, since they have the best rapport and most time with their children. The effectiveness of PST appears to be proportional to parental commitment and subject intelligence, and inversely proportional to age.

Our experience suggests that other therapists using PST equipment need training in PST's unique approach to test the complete PST program.

REFERENCES

1. Nwaobi, O.M. (1983) 'Effects of Hip Flexion Angle on the Electrical Activity of the Hip Adductors in Cerebral Palsied Children.' Bulletin for Research (UTMB, Galveston) 3(1) 6.

2. Nwaobi, O.M. (1986) 'Effects of Body Orientation in Space on Tonic Muscle Activity of Patients with Cerebral Palsy.' Developmental Medicine & Child Neurology, Vol. 28, pp 41-44.

3. Nwaobi, O.M., Brubaker, C.E., Cusick, B., Sussman, MD. (1983) 'Electromyographic Investigation of Extensor Activity in Cerebral Palsied Children in Different Seating Positions.' Developmental Medicine and Child Neurology 25, 175-183.

4. Nwaobi, O.M., Trefler, E., Hobson, D. (1984) 'Body Orientation in Space and Tonic Muscle Activity in Patients with Cerebral Palsy.' Proceedings of the 2nd International Conference on Rehabilitation Engineering, pp. 481-483.

5. Nwaobi, O.M., Hobson, D., Trefler, E. (1985) 'Hip Angle and Upper Extremity Movement Time in Children with Cerebral Palsy.' Proceedings of RESNA 8th Annual Conf. pp. 39-40.

6. Seeger, B.R. Falkner, P., Caudrey, D.J. (1982) 'Seating Position and Hand Function in Cerebral Palsy.' Australian Occupational Therapy Journal, 29, 147-152.

We gratefully acknowledge the assistance provided by K.M.C. Hospital, Manipal, India and the Chris Spencer Foundation, Vancouver, BC, Canada.

BEST COPY AVAILABLE

BUILDING SCHOOL DISTRICT CAPACITY FOR ASSISTIVE TECHNOLOGY INTEGRATION

Janice L. Weber
Center for Developmental Disabilities, UAP
School of Medicine, Department of Pediatrics
University of South Carolina

ABSTRACT

Providing services related to assistive technology to children with disabilities requires the adoption of a variety of strategies in a long term plan to make environments inclusive. It also requires strong commitment and intensive training. By developing a long term plan resulting in a trained professional staff, prepared to implement the coordination and delivery of services, a district is better able to provide inclusive education and protection from discrimination.

Because of the dearth of resources available to meet the needs of its students in the area of assistive technology applications, two South Carolina school districts formed a partnership with two agencies that will provide them with consultation, support, resource identification, training, and coordination of activities. The pilot project in progress will build local district capacity and fill a great need for information and services. After one year, the local districts will be able to assume greater responsibility for assistive technology services within their own schools.

BACKGROUND

When the Tech Act was re-authorized in the Spring of 1994, the 23 mandates to the funded states were cut to 6. The focus at this time is mainly system change and advocacy. Activities in training and direct service delivery are not viewed as part of the mandates.

This has caused significant impact. Most calls received at I&R centers are from school districts or parents of children in the schools. The main question asked is, "Can you help us?" Parents and teachers who know about the new field of assistive technology have difficulty finding services and obtaining the financial support. Because there is a shortage of trained professionals to provide the needed services, districts often have to pay for contracted services or send families out of state.

The solution proposed was to build local capacity to provide assistive technology services by a continuum of training, consultation and follow-up. Special Education coordinators from two districts approached the South Carolina Assistive Technology Project about participating in the pilot. The University Affiliated Program was invited into the partnership. Resources of state and national information services and extensive research and training expertise were then combined with the specific assistive technology activities, advocacy and system change, mandated by the Tech Act.

This project relies heavily upon the training of district personnel and parents, as well as the training of contracted personnel working in the district. The long term impact, however, will be realized through consultation with administration and technology committees in planning to integrate assistive technology into the overall educational environment.

OBJECTIVE

To assist the South Carolina Public Schools in developing local capacity to assure equal access of persons with disabilities and their families to educational opportunities via assistive technology and related support services.

METHOD/APPROACH

The training plan is based on findings from several states with training experience that were contacted for the purposes of this pilot. In the five years that Tech Act projects have been funded, many training initiatives were developed. Identified findings that appear across the board follow:

- Hands-on training is preferred over lecture by most participants.
- Educators want something to take back to the classroom for practical application and an on-going, built in support system (a number to call, a colleague to contact).
- A corps of trained people, working as a team--occupational/physical therapists, speech language pathologists, teachers, and parents--is essential for assessment of need, decisions about devices needed to fill needs, and developing IEPs.
- Most often the very basic knowledge is the place to start: explanation of technology, what is AT, what are the laws supporting it, where to buy the devices and where/how to get the money to pay for them.

Ongoing information and planning meetings with district administrators and technology committees are integral to the success of the project. It is through this component that system change will be realized. The administration and committees (composed of administrators, staff, and parents) choose the core team members to be intensively trained, and modify job descriptions and case loads to reflect the new demands. An advisory board composed of members from both districts meets quarterly to advise on the direction of the pilot.

Trainings are conducted at both awareness and skill development levels.

A two day awareness training, provided before the end of the school year, is open to any district personnel and parents who wish to attend. It addresses topics such as the following:

- Advantages of early identification and screening
- Pre-requisite knowledge and skills for user, teachers and family
- Setting educational and functional goals; IEP development
- Development and utilization of the interdisciplinary team for device incorporation into the total environment (group activities)
- Public policy, legislation, advocacy, due process
- Funding: creative strategies; establishment of cooperatives, consortia
- Resources: information, demonstration, loan libraries, etc.
- Ongoing evaluation and modification as necessary (addressed also in skill training content)

Trainers for awareness include staff of both centers as well as parent advocates and Protection and Advocacy staff.

Developing a core of "specialists" in each district, provided with specific skills and competencies to be local resources is integral to the plan for building local capacity. A variety of skill trainings will be offered throughout the summer to the designated corps of people who will serve on the assessment team and IEP team, and be on-site consultants. Participants will complete competency lists for each training chosen and be logged into a data base for referrals in peer support and consultations.

Trainers for skill development will be chosen by application after needs assessment results are completed. Technology committees will be involved. It is anticipated that some of the trainings may be large group, small group on-site, or even individual internships. Customizing to the needs of the district will drive the plan.

Evaluation of a student's educational and functional outcomes, and making modifications if necessary, will be incorporated into all trainings. Program evaluation will be conducted through the technology committees and the Advisory Board.

Teachers receive recertification credits and continuing credit hours for the trainings

It is also possible that a telecommunications system may be set up in the future. The district committees are working on plans for networking.

Existing resources of technical assistance, consultation, and information and referral services are incorporated into the training and support. The proliferation of assistive technology and its related services happens through the network of expertise established by connecting training participants to each other and making them available resources.

RESULTS:

Expected results are listed below:

Increased awareness of the benefits of inclusion and the tools available to provide it for all personnel and others involved with students in the district.

Development of specialized skills in a core of on-site personnel who can meet needs in the areas of assistive technology, environmental adaptation, public policy advocacy, and funding alternatives.

Development of the interdisciplinary team and a better understanding of its role in meeting the needs of children with disabilities.

The sustainment of ongoing follow-up, support, and training provided first through the agencies in partnership and eventually taken over by core group.

Successful incorporation of assistive technology into everyday educational instruction and environment

Increased and earlier identification of children who have technology related needs

DISCUSSION

The long term impact of this project will be significant. A comprehensive approach to system change is developed and implemented because of the partnership among agencies involved and the school district. Training is based on the team approach and all partners will participate in some level of this training effort, whether awareness level or specific skill development. District partners include teachers, students, administrators and other district staff members, as well as parents of students in special education. Other professionals at the state, regional and local level also have opportunities to participate.

Although "system change" is sometimes taken defensively as criticism that something is wrong, local school districts have instead indicated an attitude of seeking to improve and enhance what is already in place. It is the key to this strong cooperative effort and essential to its sustainment. The district will have the trained staff to continue the implementation of the project at the conclusion of the first year. On-going support will be available, but primary responsibility for program implementation will remain within the district.

The designation of a core team that will be intensively trained to make team decisions regarding assistive technology and provide consultation to teachers, students, and parents is another critical component. Work loads must be adjusted relevant to the new demands that the team members will experience. Teams are composed of at least two people from the disciplines of Occupational Therapy, Physical Therapy, and Speech/Language Pathology, a regular and a special education teacher, a technology specialist, and at least one parent. In individual cases, the student will be involved in decisions regarding this very personal use of technology.

To keep costs down, districts will be helped to develop libraries of equipment for loan to students. Information is available on forming a consortium or cooperative, or approaching funding sources for either incorporating AT into an existing technology center or establishing one via Alliance for Technology Access.

ACKNOWLEDGMENTS

Initial funding for this project was provided through the South Carolina Assistive Technology Project from the National Institute on Disability and Rehabilitation Research (grant # H224A 10031-94). Although this endeavor was the brainchild of SCATP, it could not be the system change agent it is without the following:

The work and dedication of Richland County School District I and School District V of Lexington/Richland Counties.

The AT competency lists and lab assignments provided by the Department of Special Education, Dr. Ed Blackhurst, director, at the University of Kentucky.

Training materials culled from Kentucky, Utah, Pennsylvania, Colorado, Georgia, Missouri, Idaho, Arkansas, Maryland, Indiana, and Pennsylvania.

Trainers from the aforementioned states and the following entities shared their experiences, contributed to the approach, and enhanced the content of the training:

Center for Developmental Disabilities, UAP of USC
South Carolina Assistive Technology Project
ProParent of South Carolina
American Speech Language Hearing Association
RESNA

Special recognition must be given to Sherrill Williams of Enabling Technologies, a member of the Kentucky Assistive Technology Service Network for sharing her vision of assisting school districts to increase local capacity, and the components necessary to sustain change. The KATS Network also provided the bulk of the training plan from their regional training experiences.

Janice L. Weber
Center for Developmental Disabilities
School of Medicine
Department of Pediatrics
University of South Carolina
109 Benson Building
Columbia, SC 29208 USA
803-777-9126

Inter-Agencies Service Delivery Model, Step 1

Jorge E. Letechipia (1), Kathleen A. Kolar(1), and Edward M. Frye (2)
1. Center for Assistive TEchnology, University of Pittsburgh,
2. Office of Vocational Rehabilitation, Washington, Pennsylvania District

ABSTRACT

Many authors have described procedures for agencies to conduct trans-disciplinary service delivery models . The reality of the provision of assistive technologies is that only a small number of institutions can afford to provide the full spectrum of transdisciplinary technology services. An attempt to provide a comprehensive assistive technology services through inter-agencies cooperation was developed. The Inter-Agencies Service Delivery Model consists of different service agencies providing one or more of the components of the comprehensive service delivery program. Participating agencies have identified four key steps in the implementation of this model. The first step for implementation of the Inter-Agencies Service Delivery Model, is presented in this paper.

INTRODUCTION

Many authors have described procedures for agencies to conduct trans-disciplinary service delivery models (1,2,3,4,5,6,7). The reality of the provision of assistive technologies is that only a small number of institutions can afford to provide the full spectrum of technology services.

The increased number and complexity of the existing devices often forces agencies to develop a main area of expertise within the spectrum of assistive technologies.

In addition, existing funding policies which limit reimbursement for assistive technology and the regulatory changes that the medical establishment is experiencing, are making it more difficult for agencies to implement a comprehensive service delivery program.

These realities can be seen as obstacles in the delivery of assistive technologies or opportunities to develop and implement an Inter-Agencies Service Delivery Model.

Assistive technology providers including service agencies, consumers, rehabilitation facilities and academic institutions, in the Pittsburgh and Washington, Pennsylvania area elected to explore an Inter-Agencies Service Delivery Model.

The purpose of this paper is to present the preliminary results of the organization of an Inter Agencies Service Delivery Model.

INTER-AGENCIES SERVICE DELIVERY MODEL

The Inter-Agencies Service Delivery Model consists of different service agencies providing one or more of the components of the comprehensive service delivery program.

Although the concept is simple in principle, its implementation requires a collaborative effort between agencies that in many cases compete with each other in the provision of services.

To simplify the process, the agencies identified four key steps in the implementation of these services.

Step 1. Identification of a common process to prescribe technology

Step 2. Development of an Inter Agency procedure to provide integrated assistive technology services.

Step 3. Trial client services

Step 4. Procedural refinements and full implementation of the Inter-Agencies Service Delivery Model.

STEP 1 Identification of a common process to recommend assistive technology

The first step to implement this model of service delivery is for all the participating agencies to agree on the process to provide an Integrated Personal Service Delivery Program.

The purpose of the chart presented in figure 1 is to illustrate to individual agencies the process to conduct a comprehensive and individualized service delivery program.

The chart was developed by direct service providers including rehabilitation engineers, vocational rehabilitation counselors, physical and occupational therapists and consumers.

The basic steps of Information, Screening, Evaluation and Follow-up are included in the chart. The screening processes includes the main areas of assistive technology. The outcome of the screening process is to inform the consumer and sponsoring agency whether or not there is a need to conduct in -depth evaluations. Not all clients will require an in-depth evaluation in all the areas of assistive technology. Therefore, in-depth evaluations need only be conducted in the areas identified in the screening process with authorization of the sponsoring agency. The chart suggests that some evaluations need to be conducted in sequence (Functional, Mobility, Communication, Sensory, and Cognitive issues). While others can be conducted with no particular order and driven by consumer choice.

PRELIMINARY RESULTS

The chart presented has been used as the basis for discussion on the common process to recommend assistive technology within the service delivery areas of Pittsburgh and Washington, Pennsylvania. Although it has been necessary to provide ample explanation of the implication of providing the services in this collaborative manner, there appears to be interest to pursue with the implementation of the proposed model.

Advancement toward completion of steps 2, 3, and 4 is ongoing through the Spring of 1995. A comprehensive report of the Inter Agencies Service Delivery Model is anticipated for RESNA 1995.

REFERENCES

1.Albert M. Cook and Susan M. Hussey, "Assisitive Technologies" Principles and Practice, Mosby, 1995

2. Lawrence H. Tratchman, Maggie Sauer, Project Impact: Developmen of a Statewide Service Delivery Model Through Local Capacity Building, Proceedings RESNA' 94 Annual Conference, June 1994.

3. Catherine C. Kackert and Brenda Canning, Teamwork, An Interdisciplinary Approach, RESNA Proceedings 16th Annual Conference, June 1993.

4. Lydia S. Gaster, Anthony J. Langton, L. H. Tratchman, Cooperative Service Delivery: A cost-Effective Strategy, RESNA Proceedings 12th Annual Conference, June 1989.

5. Donna Heiner and Joseph Skiba, Collaboration; A parternship for providing Assistive Technology Services in Michigan, RESNA Proceedings 12th Annual Conference, June 1989.

6. Jorge E. Letechipia, Procedure to Implement a Rehabilitation Technology Service Delivery Program, RESNA Proceedings 12th Annual Conference, June 1989.

7. Jorge E. Letechipia, Service Delivery Program at Good Shepherd Rehabilitation Hospital: A Clinical Model, Proceedings International Conference of the Association for the Advancement of Rehabilitation Technology, June 1988.

ACKNOWLEDGEMENT

This work is being developed under the auspices of the Washington District Office,Pennsylvania Office of Vocational Rehabilitation.

For further information contact:
Jorge E. Letechipia
Director
Center for Assistive Technology
UPARC
915 William Pitt Way
Pittsburgh, PA 15238

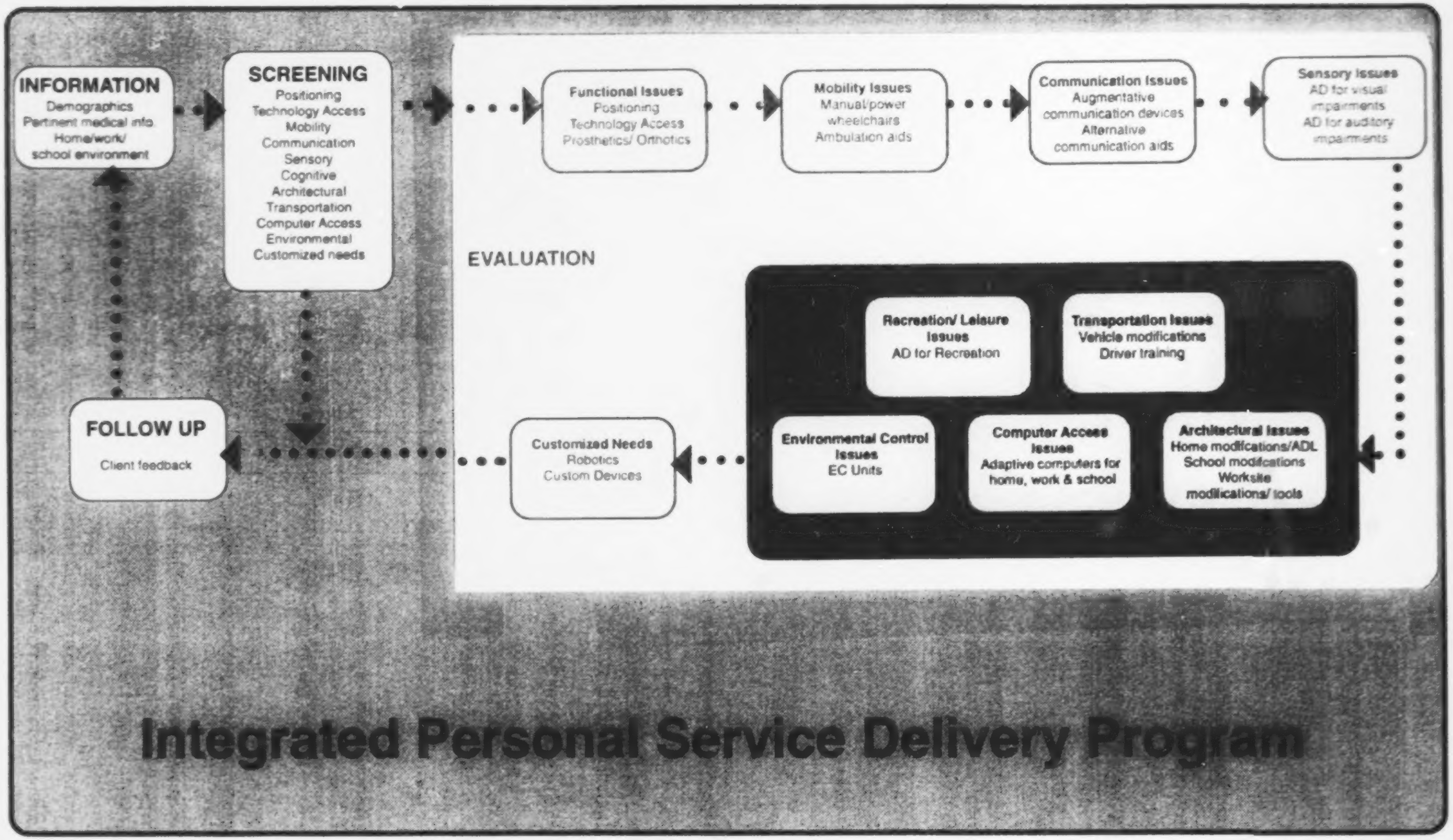


Figure 1

0001 43

BEST COPY AVAILABLE

43

BEST COPY AVAILABLE

IMPACT ANALYSIS OF THE ADVOCACY AND INFORMATION AND REFERRAL COMPONENTS OF A SERVICE SYSTEM

Bryan C. Smith, EdD and Kathy L Mayfield-Smith, MA, MBA
Center for Developmental Disabilities
University of South Carolina
Columbia, South Carolina U.S.A.

ABSTRACT:

The purpose of this paper is to introduce impact analysis to measure the outcomes of I&R and advocacy programs as required by the Tech-Act. Impact analyses use familiar measurement criteria, the relative value of money. They also use a design that has varying degrees of sophistication, but one that just about anyone can understand. It was the hypothesis of this study that an I&R system and a network of advocates had accomplished cost-effective leveraging of resources to help families with a child, or children with disabilities. The study showed that the network had positive effects. For every programmatic dollar spent, there was approximately a $27 return in outcomes, either through leveraged financial assistance or services received. The impact ratio was .036 and a correlation between costs and benefits, calculated before entry into the network, was +.098 and after, was +.309. The difference between the post-intervention and the counterfactual produced a statistically significant difference (.01) demonstrating a positive impact.

BACKGROUND

The measurement of outcomes usually determines how resources are allocated and when programs fail to measure what they have accomplished they may be in serious jeopardy of losing their support. The Technology-Related Assistance for Individuals with Disabilities Act Amendments of 1994 (PL103-218) place considerable emphasis on advocacy and information services. The task of finding funding for assistive technology devices and services is the biggest need and a major advocacy effort for the designated programs in most states. Some projects have contracted with other agencies to provide information and referral services (I&R). Others are attempting to provide these services on their own. Nevertheless, I&R programs and advocacy services are particularly vulnerable to budget cuts because it is often difficult to demonstrate tangible outcomes for these activities. The purpose of this paper is to examine a strategy that lends itself to measuring the impact of I&R and advocacy activities.

The I&R system used in this study is a central part of a network of over 100 locally based service providers (grantees). The dominant service need of families helped by this resource was for financial assistance services, primarily to help pay medical bills. Since grantees and other service providers have limited budgets and very few resources to assist in this area, entitlement programs are a key source of assistance that families could access to help themselves, however, there are a number of reasons that often block them from doing so. Many grantees served as advocates and helped families overcome this barrier, but the scope, quantity, and effectiveness of their advocacy were unknown.

OBJECTIVE

The objective of this study was to determine the impact a service network had on the families it helped by measuring costs to the network against some of the financial benefits received by families. The hypothesis was that the network cost-effectively leveraged other resources to help families of children with disabilities. Leveraging refers to the fiscally quantifiable outcomes realized by obtaining services or funds from another resource through advocacy on behalf of a family.

METHOD/APPROACH

This study was conducted in two phases. The first phase involved literature review, survey development, interviewer training, and pilot testing of the survey and the method of data collection. The second phase began with a computer-generated set of random client record numbers. Records were drawn representing individuals, not families, and the information requested in the study related only to the person represented by the selected record, even if the family's call had also involved other family members. A personalized cover letter encouraged participation by calling a toll-free number to discuss the questionnaire.

Costs included both out-of-pocket expenses paid by the family and costs accrued by the network. They were either actual or estimated and were calculated in terms of cost per unit of service. If an organization helped 200 clients in the year of the study, then the cost estimate was 1/200th of the costs of total program operation for that year. In this way, all non-capital outlay costs were factored into the estimate. Personnel resources were a principal and costly ingredient and using the total program costs per unit of service, the total personnel costs were included, rather than just the cost of the personnel involved in delivery of services.

If outcomes occurred without grantee intervention, they were not counted as a program outcome. There were monetary and nonmonetary outcomes; but as with costs, the emphasis, for this study, was on monetary outcomes. Any quantifiable outcomes that could be converted into dollar values were considered monetary outcomes. An example of a monetary outcome was money acquired from an insurance company for a child.

A regression-discontinuity design (RD) was used to interpret the data from the random sample. This design uses a frequency line graph that shows the data and regression line before and after the intervention. It is the discontinuity in the regression lines at the intervention that implies the intervention had an effect. The impact is indicated by the difference between the observed result and the counterfactual: a projection of the data into the time period occurring after the intervention point.

RESULTS

Data were collected from 52 persons in the random sample who responded to the survey. This group consisted of the parents of 44 children with disabilities and eight adults. For these individuals, a total of 152 referrals had been made based on the clients' service needs at the time they called. From the 152 referrals, 36 sample members had contacted 74 resources. Nine individuals indicated that none of the referral resources they contacted could help them and 7 did not contact any resources.

Resources to which referrals had been made were for a wide variety of services including: advocacy; financial assistance services; medical diagnosis and evaluation services; education and counseling. Families contacted referral organizations most frequently when the referral was for financial assistance and they were more likely to follow-through with any resource if a local grantee was directly involved. Over half (53.5%) the referral resources were connected to entitlement programs.

Nineteen study participants had a negative outcome, meaning the costs exceeded the outcomes. They included the nine sample members whom none of the referral resources could help and another seven who did not contact any of the resources. The remaining three had pursued the resources and received help, but the costs still exceeded the outcomes received. All members of the sample were assessed the per unit costs of all grantees who were involved in helping that sample member. For example, when study participants contacted a grantee, but did not pursue any resources, the per unit costs of the grantee and the I&R system were still assessed to them. Consequently, the minimum cost of any sample member was the per unit cost of the I&R system. Thirty-three of the fifty-two study participants (63.5%) had a positive result, meaning their outcomes exceeded their related costs. The range of leveraged outcomes was from $395 to $109.580. The arithmetic mean, or average, was $13,787.

Thirty-four of the children in the study were between the ages of 5 and 21, making them eligible to receive educational services in most states. Twenty-two respondents indicated that school services had changed in a positive manner for them since calling. The value of each school service, such as special education, homebound instruction, physical therapy, and speech/language therapy, was calculated from the frequency of the service multiplied by the estimated cost per hour of each service. When a child was in a regular class and was moved to a special education class, the cost difference between the two programs was used as the estimate of the schools' cost and resulting benefit to the family. When schools did not provide an actual or estimate of these costs, the average of all the other schools' costs for providing the same service was used for that particular program.

All financial resources, except for education and Medicaid, were consumer self-reported as the amount of money they received. The dollar value of education services was estimated, and the Medicaid amount was the amount reported as received by the consumer. Three children who were awarded Zebley back payments from SSI received: $3,500, $80,000, and $87,000. Two study participants needed assistive devices: one a communication device ($395), and the other a motorized chair ($2,095).

A correlation between costs and benefits, calculated before entry into the network, was +.098 and after was +.309. These correlations can be interpreted as showing a slight positive relationship between costs expended and benefits received before the intervention, and a stronger positive relationship after the intervention. To describe the intervention effect, a regression analysis produced a pre-intervention slope of 0.246 and a *y* intercept of

1,563. The post-intervention slope was 1.89 with a *y* intercept of 10,857.

The discontinuity in the regression lines implies that the intervention had a positive effect. The vertical change suggests a main effect and the change in slope shows an interaction effect. The magnitude of the effect can be obtained from an impact ratio, which is the ratio of the costs incurred contrasted with the monetary outcomes associated with the efforts of the network. The impact ratio was .036. A benefit cost ratio showed that for every dollar spent on services and equipment for this study group, there was a $27.58 return in outcomes, leveraged through either financial assistance or services.

The difference between the post-intervention and the counterfactual produced a t-test value of 3.698 (2.457 tabled t value for a one-tailed test). The obtained difference was statistically significant; i.e., there is little likelihood--less than one percent probability--that a difference could have resulted from a chance variation between the counterfactual and post-intervention.

DISCUSSION

Impact analysis was chosen for this study because it is a method used to determine the relationship between the costs of an initiative and its effect. It is a systematic approach to evaluating the relative outcomes of a project; and it examines the costs, benefits, and uncertainties to determine if the initiative was beneficial in meeting its objective. Impact analyses, like cost-effectiveness or cost-benefit studies, are estimates and as such, the conclusions drawn are subject to the level of accuracy of the data used.

This study was conducted to measure the degree to which the network had leveraged resources to help families. Because the resources were reported by the families who received them, there is a certain degree of inaccuracy to these data. An example of this is the possible under-reporting of Medicaid. Medicaid is not a monthly amount received by the family, and is paid directly to the service provider, the family may not have known the exact amount paid.

A threat to external validity may have been introduced by the volunteerism that resulted in 34.7% of the random sample participating in this study. This small response limits the ability to make an inference of the findings from the sample to the population from which they were drawn. This raises the question of how would these results have changed if there had been a 100 percent response. Ten non-respondents were able to be contacted by telephone to determine why they chose not to participate and to see how their costs and benefits differed from the data collected from other members of the random sample. The common explanations for non-participation included a range of reasons, two of which seemed most relevant to this study: (1) because their service needs had been met, they wanted to be left alone and desired no further involvement with any organization; and (2) they believed that the amount of money a family gets and how they spend it are private. Interviews with these ten non-respondents, revealed that the benefits they received were greater than zero, and their involvement with the network, indicating costs to the network, was similar to the respondents'. From these few follow-up interviews, it appeared that non-respondents probably introduced bias that underestimated the acquisition of benefits, and the $27.58 is a realistic finding.

Referrals to service resources for the study group had been made to meet the clients' total service needs, not solely with the intention of obtaining financial support. That grantees had considerable success in leveraging may be due to their unique skills in advocating and interpreting how various agencies and processes work and their knowledge of how to best navigate through various bureaucracies to access resources and services to which family members are entitled. It may also be an indicator of the underserved nature of this population inferred by the apparent failure of the traditional system to champion the issues to obtain entitlements.

There is no question that accountability and impact are programmatic goals that need to be continuously addressed. Traditionally they are either left to the end of a program or ignored. A proactive approach to evaluation by technology-related assistance programs would be as programmatically innovative as the intent of PL 103-218 on the lives of persons with disabilities.

ACKNOWLEDGMENTS

Program funding was provided by the Agent Orange Class Assistance Program. Thanks to Mr. M. Leaveck, Ms. Dawn Sudduth, and all the participating members of the network for their invaluable contributions to this work.

Bryan C. Smith,
Center for Developmental Disabilities
Benson Building, Columbia, SC 29208
Phone: (803) 777-4469 FAX: 777-6058

TRANSITION TO COMMUNITY LIVING: AN ASSESSMENT OF ASSISTIVE TECHNOLOGY NEEDS AND COSTS

Laurel S. Mendelson, Tamar Heller, Claude Jacob, and Meredith Watkins
Institute on Disability and Human Development (UAP)
University of Illinois at Chicago, Chicago, Illinois

ABSTRACT

As a result of OBRA-1987, States are required to provide services to enable the transition from nursing homes to community residences for people with developmental disabilities. This process is often facilitated by the use of assistive devices especially in the areas of seating and mobility, augmentative communication, and activities of daily living. In the study reported here, more than 80% of nursing residents with developmental disabilities required assistive technology. With this equipment, nearly all nursing home residents can move to supported residences in the community. In most cases, the necessary equipment is readily available and reimbursable through Medicare or Medicaid.

BACKGROUND

Under the mandates of the Nursing Home Reform Amendments of the 1987 Omnibus Budget Reconciliation Act (OBRA 1987), PL 100-203, States were required to develop systems to move people with disabilities from long-term care facilities into appropriate community residences. In response to this legislation, Illinois passed the Community-Integrated Living Arrangements (CILA) Licensure and Certification Act in 1988 to promote community placement of people with developmental disabilities and mental illness. Among the provisions of the Act are guarantees of evaluations and adaptive equipment to facilitate transition into the community (see companion article by Brenda Sposato).

Previous studies have shown that most individuals with developmental disabilities currently living in nursing homes could benefit from some assistive technology. In some cases, the application of equipment can improve independent function to a point where an individual can be discharged to an independent living situation (1).

Advocates of the CILA program believe that community residence will lead to increases in education, jobs, civic responsibilities, social contacts, and recreational opportunities. Studies by Heller et. al. demonstrated that individuals with developmental disabilities who moved into community residences received higher wages, achieved greater community inclusion, and suffered fewer health problems or mobility limitations than those who stayed in nursing homes (2).

But despite the success of community placement, the transition to community living has been delayed in part due to fears that inclusion will be complicated and costly. In particular, the overall needs for assistive devices and the types of equipment that could prove beneficial are not known.

In this study, we examined the types of assistive technology that are needed by individuals with developmental disabilities who are moving from nursing homes into the community, and we identified some of the costs of obtaining this equipment.

OBJECTIVE

The purpose of this study is to determine the extent of assistive technology needs of nursing home residents with developmental disabilities, to identify the types of equipment that will meet these needs, and to specify the costs and sources of funding for such equipment.

METHOD

The study population included all nursing home residents with developmental disabilities on Chicago's North side who were at least 30 years old. A total of 268 individuals met the requirements and agreed to participate. The majority of the participants had severe to profound mental retardation and approximately half had cerebral palsy. Participants were surveyed in 1989-1990 and in 1992-1993 to determine their functional abilities, living arrangements, and service needs using the Inventory for Client and Agency Planning (ICAP). Approximately 25% of this population has been referred to the Assistive Technology Unit to date, and those individuals have also received comprehensive clinical evaluations of their physical abilities and needs for adaptive equipment.

Additional data was collected from other CILA clients with similar diagnoses and needs who were evaluated at the ATU from outside the study population during the same time period. The data presented here were collected from survey results and clinical reports.

RESULTS

Based on the results of the ICAP, approximately 83% (222 individuals) of nursing home residents with developmental disabilities have deficiencies in mobility, communication, or activities of daily living that could be ameliorated through the use of assistive technology. Despite these needs, very few of the study participants owned adaptive equipment. We found that 58% (155 individuals) required seating and mobility intervention, 56% (149 individuals) required augmentative communication services, and 59% (158 individuals) required equipment to assist with activities of daily living.

The foremost issue that must be addressed prior to moving from the nursing home is independent mobility. Until recently, most residents used wheelchairs belonging to the facility, and needed to acquire their own prior to community placement. Of those individuals needing seating and mobility equipment, the most commonly-prescribed devices were manual wheelchairs with customized seating systems. Other technology that was occasionally recommended included power wheelchairs, tilt-in-space or recline units, and walkers. The costs for wheelchairs ranged from $965-$11,704, with a median cost of $1,331. The costs for seating systems ranged from $356-$2,108, with a median cost of $1,070. In most cases, seating systems were funded by the Illinois Department of Public Aid (Medicaid); costs of wheelchair bases were funded by both Medicare and Medicaid.

56% of nursing home residents are unable to communicate effectively without assistance. Recommendations for augmentative communication ranged from individualized instruction in choice-making to complex electronic devices. The equipment most commonly recommended in the nursing home setting was letter or picture boards or notebooks. This relatively low-tech equipment was often used to predict whether more complex equipment could be used in the future. Many individuals in the nursing home setting were never given the opportunity to learn basic communication strategies, and so were not prepared to benefit from more complex interventions. Of those individuals who did require augmentative communication equipment, costs ranged from $102-$5,693 with median cost of $2,020. Until recently, there were few opportunities to fund this type of equipment, but under threat of a class action suit, the Illinois Department of Public Aid has recently agreed to cover this equipment.

Many nursing home residents depend on staff for bathing, dressing, eating, or other activities of daily care. In most cases, we deferred evaluations for ADL equipment until an individual was in a community residence. Equipment most commonly prescribed included devices to assist in bathing and environmental controls. Costs of equipment ranged from $3-$1,002. Median cost of ADL equipment was $40. ADL equipment is generally reimbursable by Medicare and Medicaid.

A summary of the mean, median, and ranges of costs is given in table 1.

Table 1. Mean, Median, and Range of Costs of Equipment for CILA Population

	Type of Equipment			
	WC	Seating	AAC	ADL
Mean	$2,087	$1,141	$2,422	$325
Median	$1,331	$1,070	$2,020	$40
Range	$965-11,704	$356-2,108	$102-5,693	$3-1,002

DISCUSSION

Many people with developmental disabilities have functional limitations in mobility, communication, or activities of daily living. Until recently, impairments in one or more of these areas precluded community living. With the passage of community integration legislation and the improved access to assistive technology, most members of this population can now live in supported living situations in the community.

Initial assistive technology evaluations generally occur while an individual still resides in the nursing home. Recommendations in this setting involve equipment that is necessary for the individual to move out of the facility, including wheelchairs and seating systems, devices to assist with basic self-care activities such as feeding and dressing, and strategies for rudimentary communication. Once in a community residence, experiences and needs change. Homes must be adapted to allow wheelchair access and to maximize independent function. Skills must be cultivated in the areas of telephone usage, meal preparation, money management, and job tasks. Social and recreational pursuits must be developed. Because community residents have so many new opportunities, their need for assistive devices must be re-evaluated; it is possible that new equipment will be required.

Assistive technology can significantly increase the independence of people with disabilities. In many cases, adaptive equipment can be the determinant for deciding between residential or community placement. This in turn can make the difference between segregation and full community integration.

REFERENCES

(1) English, J.B., K.H. Knorr, J.Z. Schuch, "Rehabilitation Engineering Technology Applied in a Total Care Facility: A Feasibility Study." Proceedings of RESNA 8th Annual Conference, Memphis, TN, 1985.

(2) Heller, Tamar, Alan Factor and Joan Hahn, "The Impact of Residential Transitions Out of Nursing Homes for Persons with Developmental Disabilities." Submitted for publication, 1994.

ACKNOWLEDGEMENTS

The evaluations and recommendations summarized in this report were performed by the staff of the Assistive Technology Unit at the Institute on Disability and Human Development (UAP) at the University of Illinois at Chicago, including Glenn Hedman, Brenda Sposato, Roberta O'Shea, Mary Angelico, Laurel Mendelson, Patricia Politano, Deborah Lundy, Tracy Nakashima, Stephanie Doster, Beatrice Parker, John Van Gorder, and James Bullock. Assistive technology evaluations were funded by the Illinois Department of Mental Health and Developmental Disabilities.

This project was funded by the U.S. Department of Education, Office of Special Education and Rehabilitation Services, National Institute on Disability and Rehabilitation Research (grants numbers H133B30069-94 and H133B30072-94).

Laurel S. Mendelson
Institute on Disability and Human Development
The University of Illinois at Chicago
1640 W. Roosevelt Road
Chicago, IL 60608

AN ASSISTIVE TECHNOLOGY PROGRAM IN RESPONSE TO OBRA-87

Brenda A. Sposato, MEBME, Glenn Hedman, M.Eng.
Assistive Technology Unit
Institute on Disability and Human Development (UAP) / University of Illinois at Chicago

ABSTRACT

Approximately 82,942 individuals live in nursing homes in the state of Illinois (1). Many are individuals with developmental disabilities who do not require ongoing medical care but rather high levels of personal care. In response to OBRA-87, the Illinois legislature passed the Community Integrated Living Arrangements (CILA) Licensure and Certification Act (PL 86-922). The state's Department of Mental Health and Developmental Disabilities (DMHDD) was the agency mandated to implement the CILA program. Through the efforts of the University of Illinois at Chicago Institute on Disability and Human Development (UAP), assistive technology was identified by DMHDD as a critical service to assist an individual in the transition from the nursing home to an independent living arrangement in thecommunity.

BACKGROUND

Traditionally, an individual was placed in a skilled nursing facility based on a need for ongoing medical care. However, not all nursing home residents required the full extent of these services. Many people with developmental disabilities have functional limitations which require high levels of personal care more often than high levels of medical care.

The Nursing Home Reform Act (OBRA-87, PL 100-203) passed in 1987, mandated that every nursing facility receiving federal funds undergo an annual review of all residents' individualized needs. In this way, a correlation would be drawn between care needs and level of services provided by the facility. Additionally, OBRA-87 mandated that individuals with developmental disabilities who *do not* require skilled nursing care but who *do* require support and/or specialized services be given a choice to move to a more appropriate residence (2). Under OBRA-87, each state is responsible for providing the services necessary to support community living.

In 1988, the Illinois legislature passed the Community Integrated Living Arrangements (CILA) Licensure and Certification Act (PL 86-922). The Illinois Department of Mental Health and Developmental Disabilities (DMHDD) was the agency mandated to implement the CILA program. DMHDD identified Pre-Admission Screening / Annual Rehab Review (PAS/ARR) agencies to provide case management services to locate the individuals and arrange for appropriate services. Through the efforts of the University of Illinois at Chicago Institute on Disability and Human Development (UAP), assistive technology was identified by DMHDD as a service that could assist an individual in the transition from the nursing home to an independent living arrangement in the community. For the individual choosing to remain in the nursing home, assistive technology could still assist the individual in maximizing independence.

While DMHDD is responsible for funding the evaluation services, in most cases, the Illinois Department of Public Aid (and Medicare when applicable) provides funding for the acquisition of equipment.

OBJECTIVE

The objective of this project was to design a service delivery program that would assist individuals in the CILA program in the transition from the nursing home environment to the community. The program design includes how and where the services would be delivered, the equipment necessary for evaluation, processing of evaluation documentation within the state system, equipment delivery and follow up.

APPROACH

Beginning in 1991, DMHDD has contracted the Assistive Technology Unit (ATU) at the University of Illinois at Chicago Institute on Disability and Human Development (UAP) to perform assistive technology evaluations for the CILA-identified individuals in the six-county area of northeast Illinois. In some cases, when clients could be grouped together in one location, ATU clinicians have travelled as far as 120 miles away form the in-house clinic. Overall, the Assistive Technology Unit provides evaluation services in the areas of Activities of Daily Living (ADL's), Augmentative Communication, Computer Access, Environmental Control Units, Home Modification, Seating and Wheeled Mobility and Worksite Modification. The areas most frequently requested by the PAS/ARR agents include Activities of Daily Living, Augmentative Communication and Seating and Wheeled Mobility. The DMHDD contract was designed to cover the cost of the evaluation(s) *only* for a particular individual. When applicable, the individual's state funding source was utilized for acquisition of the equipment.

Each individual is referred to the ATU via the assigned PAS/ARR agent. A background information questionnaire specific to the evaluation requested is sent to the appropriate person(s) involved with the individual. Upon receipt of this document, the client is scheduled for evaluation. When possible, clinicians work in teams for a comprehensive assessment. Approximately 90% of the clients are evaluated in their home, school or work environment. This allows those individuals working with the client and/or those most invested in the client's care to contribute to the evaluation and equipment selection process.

ATU services are rendered with the use of seven mobile units which include three vehicles adapted for fabrication purposes (Figures 1 and 2). In most cases, mini vans are used for augmentative communication and ADL evaluations and implementations. Seating and Wheeled Mobility services are delivered with the vehicles equipped for fabrication. This makes it possible to modify or fabricate equipment on site eliminating delays in system delivery.

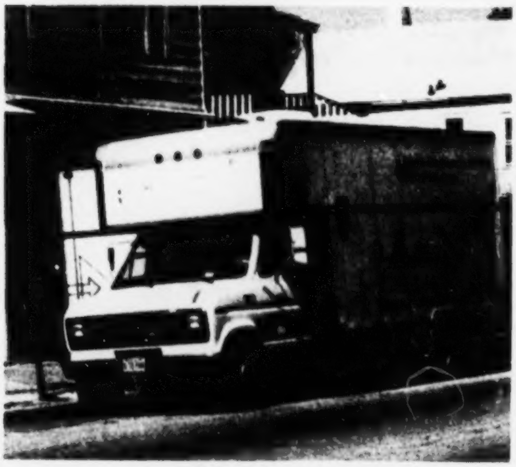


Figure 1

Once the evaluation(s) is complete, clinicians compile the necessary documentation to submit to the appropriate funding source to obtain prior approval for payment of the recommended equipment. During the first two years of the program, only prior approvals for recommended seating and wheeled mobility equipment were granted by the state's Department of Public Aid (within set price allowables). Requests for payment of recommended augmentative communication equipment were denied based on the state's policy for denying funding of all communication systems. In addition, the requests for payment of the recommended ADL equipment were denied based on the state's determination that purchase of these items had already been included in the individual's annual CILA rate. (The CILA rate is defined as the amount of money awarded per person per year based on individualized needs.)

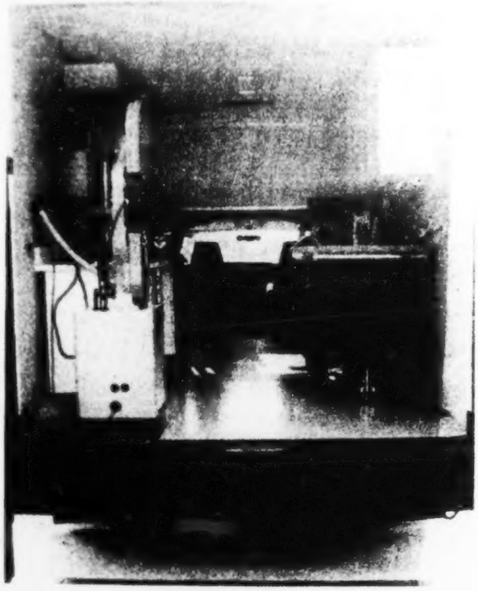


Figure 2

In 1993, a class action suit, Bogard v. Bradley, was settled with significant benefits regarding funding of the previously denied items for some of the CILA individuals in this program. This suit was filed in 1988 against five agencies in the name of nearly 3200 nursing home residents with developmental disabilities. The suit claimed that the State of Illinois discriminated against this population and failed to provide them with appropriate placements and services. At present, communication systems for Bogard class members are funded by the state Department of Public Aid (within set price allowables). For non-Bogard class members, however, the process is currently under revision. Funding denials for communication equipment for the

CILA individuals accumulated. The State of Illinois was threatened with another class action suit. As a result, the state's Department of Public Aid is currently developing a new policy with guidelines for acceptance of funding of communication systems. With regard to the funding of ADL equipment, the state's policy has not changed when the equipment involves items purchased "off the shelf". In the case of custom fabricated items, the state will review each payment request on a per case basis.

DISCUSSION

Individuals in the CILA program continue to receive evaluation services and equipment implementations by the ATU. Many individuals initially evaluated in a nursing home moved into independent living environments within the community along with their equipment. A review of the equipment needs and the associated costs are given in the accompanying article by Laurel Mendelson.

REFERENCES

1. Cornelius, Betty, Health Care Financing Administration, Personal correspondence, 1995.

2. Mendelson, Laurel, *Assistive Technology and the Transition to Community Living*, Impact, December, 1994.

ACKNOWLEDGEMENTS

Support for the Assistive Technology Evaluation services was provided by the Illinois Department of Mental Health and Developmental Disabilities (DMHDD).

Work of the Assistive Technology Unit is made possible by the Illinois Department of Mental Health and Developmental Disabilities (DMHDD), the Illinois Department of Rehabilitation Services (DORS), the United States Department of Health and Human Services - Administration on Developmental Disabilities (ADD), and the University of Illinois at Chicago.

Brenda A. Sposato, MEBME
Assistive Technology Unit
Institute on Disability and Human Development (UAP)
University of Illinois at Chicago (M/C 626)
1640 W. Roosevelt - Room 412
Chicago, IL 60608-6904
(312) 413-1555 (V)
(312) 413-1554 (TDD)
(312) 413-3709 (FAX)

THE REHABILITATION TEAM: A SYSTEMATIC APPROACH FOR USE OF TECHNOLOGY IN VOCATIONAL REHABILITATION SERVICES

Neil F. Lown
Center for Rehabilitation Technology Services
West Columbia, SC

Abstract: Although assistive technology has been around for years, its use has recently begun to proliferate. However, rapid growth tends to retard the development of a systematic approach that facilitates coordinated delivery of services. This article proposes a systematic approach to the application of assistive technology, one that takes advantage of the strengths of key members of the rehabilitation team.

Background

In situations where assistive technology is an issue in meeting employment goals, there are three main service providers available to assist vocational rehabilitation clients in becoming successfully employed. There is the vocational rehabilitation counselor; the vocational evaluator; and (when available) the assistive technology practitioner. Each of these entities has a unique set of skills; however, no one of them can possibly have all of the knowledge and skills at his/her disposal to determine the need for appropriate assistive technology, to apply the technology, and to facilitate job placement. For this reason, it is essential that a team approach be developed to pull together all of the necessary expertise to make successful use of assistive technology. The vocational evaluator is in a position to be the central member of this team. Vocational evaluators provide client assessment services which assist the VR counselor in identifying appropriate job options. However, vocational evaluators do not solicit clients; they provide services only to those clients referred to evaluation by the VR counselor. Similarly, assistive technology practitioners do not become involved in cases until they are called upon by a counselor or other VR professional. Due to this fragmented (non) system, assistive technology is utilized only if some unspecified VR professional happens to think that technology might provide a solution. Generally speaking, there is no process in place wherein a central figure makes a determination that an assistive technology intervention may be appropriate.

According to Langton (1991), "Establishing a 'technology team' comprised of staff from varied backgrounds would be a feasible way for large facilities or agencies to provide these services" (p.5). Reed, Fried, & Grimm (1993) state that "Realizing that in most cases it may prove impossible for the evaluation staff to master all of the many, diverse areas of assistive technology, the staff might want to consider developing a network." (p.218). Chubon, Stewart, and McGrew (1991) state that "Whether or not assistive technology will benefit persons with disabilities is largely dependent upon counselors and other evaluators becoming knowledgeable of its use and aware of supporting resources, particularly rehabilitation engineering services." (p. 258)

The need for vocational evaluators to assume a key role in the technology team is documented in a number of sources. Langton notes that "...the vocational evaluator could be the connecting link necessary to make more effective use of technology resources. With skills in assessment and job analysis techniques, the vocational evaluator is well qualified to identify the need for assistive technology and to match these needs with available resources." (p.6) Reed et al. noted that "Individuals and evaluation/assessment programs that have positioned themselves to effectively address technology questions will be in demand." (p.220)

Chubon et al. called for vocational evaluators to increase their role in bringing assistive technology into the vocational rehabilitation process, stating that "Although [recent] assessment developments are impressive, there are areas [of vocational evaluation] where progress has not kept pace. These include consideration of the extent to which technology can enhance the functional capacity of persons with disabilities, and the extent to which technology can be used to accommodate diminished functional capacity through adaptations in the work place." (p.255)

Problem Statement

Traditionally, vocational rehabilitation counselors have placed clients with visible job skills in employment, providing counseling and guidance, physical restoration, and training when appropriate. If there are functional limitations that prevent the client from performing a given job, or if the VR counselor is uncertain as to the client's ability to perform a given job, the traditional referral has been to avocational evaluator. The evaluator's job is to determine the extent of the client's functional limitations and to determine vocational goals that are realistic for the client based on these functional limitations. However, vocational evaluators have traditionally recommended employment fields that did not require functioning in the areas of functional limitation. The availability of

BEST COPY AVAILABLE

rehabilitation technology aids and devices has made it possible for vocational evaluators to consider another avenue for making vocational recommendations; the recommendation for assistive aids or devices that would permit a client to perform a given task regardless of functional limitations. That is, the evaluator can recommend that a rehabilitation engineer or other assistive technology provider be consulted to prescribe a rehabilitation technology intervention, possibly a piece of assistive technology equipment that would negate the functional limitation.

In order for this to happen, however, there must be a team approach that is geared towards bringing together the necessary expertise to consider the use of assistive technology when appropriate. Presently, it appears that technology is utilized only when there is an interested individual somewhere among the ranks of VR counselors or evaluators.

Approach

In order to consider an approach, it is first necessary to look at the major entities and to determine their strengths. By utilizing this method, it is possible to develop a systematic approach that fully utilizes each participant's unique skills and abilities to the client's best advantage.

The VR counselor excels in eligibility determination, counseling and guidance, service planning (IWRP development), employer liaison, job placement, and follow-up. Counselors tend to have large caseloads, and therefore the majority of their energies must be devoted to case management. If the counselor is able to place a client with no barriers to a chosen job field into employment, he/she will do so, providing counseling and guidance, training, or other substantial services. However, if the counselor is uncertain as to the abilities and interests of the client, a referral will be made to a vocational evaluator.

The vocational evaluator is proficient at assessing job skills, determining strengths and weaknesses, assessing interests, assessing physical and mental abilities, and recommending vocational objectives. When making vocational recommendations, the evaluator does so in light of the client's functional limitations. Therefore, a decision that must be made by the evaluator is whether employment recommendations must be in areas that do not require functioning in deficit areas, or if the application of assistive technology can assist the client in overcoming the functional limitations and enable him/her to successfully perform job tasks by utilizing an assistive device. Once the evaluator determines that technology may be helpful, a referral is made to an appropriate assistive technology practitioner.

The assistive technologypractitioner may come from any one of several fields, depending upon the area of the functional limitation under consideration. Possible areas of expertise include ergonomics, seating and positioning, knowledge of existing assistive devices, ability to adapt existing devices, ability to fabricate devices, communications, computer utilization, etc. A.T. practitioners may come from a variety of backgrounds, including engineering, OT, PT, speech/language pathology, industrial design, computer science, etc. This person's job would be to consider input from the vocational evaluator, to provide a device or other accommodation to enable the client to perform a given task, and to train the client in its use when appropriate.

It is recommended that a systematic approach be implemented that would ensure that technology is considered in cases where it may be appropriate. Under this approach, the counselor would directly place clients who have clear vocational objectives into employment without involving other members of the technology team. If vocational objectives are questionable, the client would be referred to the vocational evaluator. If, in the course of the evaluation, the evaluator determines that technology could be utilized to assist the client in entering employment, the evaluator would call in the appropriate A.T. practitioner based upon the area of the functional limitation. This approach would ensure that the utilization of technology would not be merely a chance occurrence by designating the vocational evaluator as the professional who (based upon behavioral observation) determines that technological intervention may be appropriate. This is not to say that a VR counselor may not recognize the need for technology earlier in the process; if this recognition occurs, the VR counselor may decide to call upon an A.T. practitioner earlier in the process. However, utilizing this systematic approach would increase the chance of the introduction of technology into the client's rehabilitation plan by ensuring that a protocol is in place that would facilitate its consideration at some point.

As with any new initiative, training will be a central issue. To specify the vocational evaluator as the central referral source without equipping the evaluator with the knowledge and awareness of the utilization of assistive technology would be to ensure the failure of the system.

Implications

A technology team approach would make better use of existing resources. It would ensure that technology is considered in all cases wherein it may be appropriate, and it would ensure that the utilization of appropriate professionals was optimized. This would,

BEST COPY AVAILABLE

in turn, create more client satisfaction, since many jobs that may have been ruled out in the past will still be considered, adding to the list of potential vocations and giving the client more choices.

Discussion

The VR counselor provides an array of substantial services to a large number of clients. While the counselor may be interested in assistive technology, he/she is not in a position to recommend technology, since it would be necessary to observe the client's behaviors over a significant period of time in order to assess the necessity and appropriateness of technology. The vocational evaluator, on the other hand, has the client under observation from one day to two weeks, depending on circumstances (Flynn, 1994). The evaluation process enables the evaluator to observe the client's adaptive behaviors and to formulate ideas as to technological interventions that could assist the client's natural attempts at overcoming his/her functional limitations.

Once the decision is made that the use of rehabilitation technology is a feasible solution, the evaluator will then decide which AT practitioner to call upon to recommend, adapt, or fabricate a device or other appropriate worksite modification. The AT practitioner will then provide the device or other intervention, train the client, and set up the work site. At this point, the VR counselor begins follow-up, ensuring employer and client satisfaction, monitoring the situation for any needed adjustments. The vocational evaluator's job is completed for this client; the A.T. practitioner will be called upon again only if there is a need for adjustment or reassessment of the adaptation.

By utilizing this team approach, each entity will be used to its full potential. The use of technology in vocational rehabilitation will be maximized. However, the biggest winner will be the client, who will have a much better chance of working in a rewarding occupation rather than having to settle for a less than satisfying job due to some physical limitation that is unaddressed by assistive technology.

References

Chubon, R.A., Stewart, W.W., & McGrew, G.W. (1991). The Implications of Technology for Vocational Assessment. *Rehabilitation Education*, Vol. 5, pp. 253-259.

Flynn, C.C. (Ed.) (1994). *Rehabilitation Technology Services in Vocational Rehabilitation Agencies Survey*. West Columbia, SC: Center for Rehabilitation Technology Services.

Langton, A.J. (1991). Making More Effective Use of Assistive Technology in the Vocational Evaluation Process. *Issues & Applications in Assistive Technology*. West Columbia, SC: Center for Rehabilitation Technology Services.

Reed, B.J., Fried, J.H., & Grimm, R.L. (1993). Expanding the Vocational Evaluation Process Through Assistive Technology. In R.R. Fry (Ed.), *National Forum on Issues in Vocational Assessment*. (pp. 217-220). Madison, WI: University of Wisconsin-Stout, Materials Development Center.

Acknowledgements

The Center for Rehabilitation Technology Services (CRTS) is part of the SC Vocational Rehabilitation Department. Support for this work has been provided through the National Institute on Disability and Rehabilitation Research (NIDRR), U.S. Department of Education, Washington, D.C. as part of the rehabilitation engineering research center grant #H133E20002-95.

Neil F. Lown
Center for Rehabilitation Technology Services
SC Vocational Rehabilitation Department
1410-C Boston Avenue
West Columbia, SC 29171

BEST COPY AVAILABLE

ACCOMMODATIONS FOR PERSONS WITH MENTAL DISABILITIES

Kali Mallik & George Elder
Alliance, Inc., Baltimore, MD

ABSTRACT

Accommodations in terms of aids and devices are targeted generally for individuals with physical disabilities. Either the rehabilitation engineering practitioner may easily conceptualize the environmental demands to make a person with physical impairments become productive or persons with mental disabilities are not capable of expressing their needs for devices. The environment may be work, home or an educational or recreational site.

The purpose of this paper is to address the needs of people with mental retardation and mental illness at in regards to devices related to work and educational environments.

INTRODUCTION

The publication on accommodations for persons with mental disabilities places emphases on adaptive behaviors, stress management, communication skills, empowerment, supervisor/co-worker training and less on assistive devices (Porter, 1993). There are some Occupational Therapists experienced in providing accommodations for functional problems among psychiatric disabilities. The functional aspect they cover are in the areas of self efficacy, duration of concentration, screening out of environmental stimuli, maintaining stamina throughout the workday, managing time pressure and deadlines, initiating interpersonal contact, focusing on multiple tasks simultaneously, and responding to negative feedback (Crist & Stoffel, 1992). Architectural changes including installing additional entrances, brightening paint, changing lights, and allowing rooms for privacy may significantly improve the functions of persons with psychiatric disabilities (Gutkowski, Ginath & Gurrman, 1992).

The mission of Alliance is to provide services and opportunities to people with disabilities which empower them to reach social and economic growth. There are over 600 consumers being served annually, of which mental illness, mental retardation, dually diagnosed, and others represent 46%, 13%, 10% and 31% respectively. Rehabilitation engineering services in providing aids and devices are an integral part of the rehabilitation process (Mallik/Stinson, 1994 and Mallik/Elder, 1993).

The following case studies evidence how persons with mental retardation and mental illness can gain their functional independence in work and educational environments:

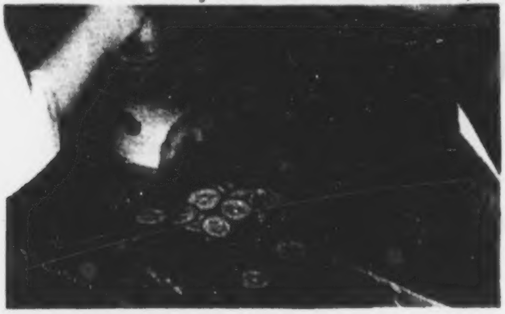
Case Study #1
JC, 24 years old, with mild mental retardation obtained employment at a local restaurant in a mall doing food preparation. The main challenges for JC in maintaining employment are attention deficit problems, poor motor coordination and having left ear hearing impairment.

JC progressed in the job tasks using sharp knives for food preparation. Unfortunately, both attention deficits and poor manual dexterity became issues of concern in safety and productivity. Medication assists JC to focus longer on difficult tasks but there were problems cutting certain fruits and vegetables to a consistent size and width. Alliance's Job Placement staff and Job Coach were in constant surveillance on JC's progress. Along with the most cooperative help from the employer, they felt that possibly a mechanical device might be helpful.

A Product Designer at Alliance came up with a design for a manual slicer which gives more stability to the knife blade for straighter cuts. Many factors came into play in the assembly of JC's slicer. Because of its use with food products, only certain materials could be used: stainless steel and butcher's block. The butcher's block was easy to locate. Grinding of America, Baltimore, Maryland, graciously modified the necessary size knives for the slicer by drilling holes in them and sharpening them free of charge.

A difficult part of the slicer was locating an appropriate bracket. After much effort, Buchanan-S Tube Bending Co., Baltimore, Maryland, fabricated stainless steel brackets. A plastic guide was added to ensure consistent width of slices.

Finally, the day came when an anxious JC could try the new slicer. We are very excited to report that this is a success story for JC as well as Alliance, Inc.

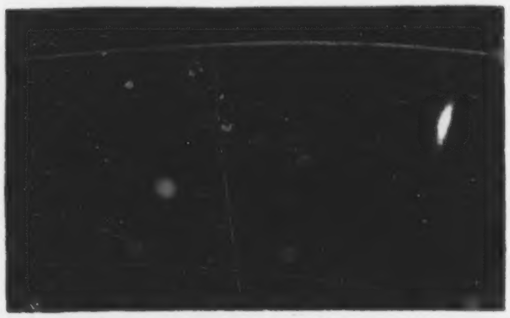


Picture #1: A manual slicer
Cost of Materials: $75
Design/Fabrication Time: 25 hrs.

Case Study #2
JT, 32 years old, is diagnosed as having manic depression and is under psychiatric care. The depression is controlled under medication but side effects include dryness of the mouth.

JT, a student at the Community College, wanted to play the oboe in the college's orchestra. She was unable to fulfill this desire due to the lack of saliva needed to play her instrument. Alliance, Inc. was able to furnish JT with a method of supplying the necessary saliva. JT now has a foot operated treadle (similar to a car's gas peddle). By pressing the treadle, JT can supply the required saliva to her mouth. The subjective saliva is an over-the-counter product sold in a drug store. The pressing upon the treadle forces the saliva through a tubing and check valve to an adjustment bracket attached to a special hat that then goes to the corner of her mouth. JT expressed her appreciation saying, "This allows me to pursue a prime interest that I have - playing in the school's orchestra." A Psychiatrist has been working with JT for 8 years and has stated, "This has helped JT with her self esteem and now she has taken a focus on the reality of her life."

Picture #2: JT playing the oboe



Picture #3: Foot operated treadle
Cost of Materials: $99
Design/Fabrication Time: 38 hrs.

CONCLUSION

There are many consumers like JC and JT who could benefit from the rehabilitation engineering products, once consumers, rehabilitation professionals, employers, and others are oriented about its impact of resources.

For further information:
Alliance, Inc.
7701 Wise Avenue
Baltimore, MD 21222
(410) 282-5900
(410) 282-3083 (FAX)

REFERENCES

Crist, PAH; Stoffel, V.C., The Americans with Disabilities Act of 1990 and Employees with Mental Impairment: Personal Efficacy and the Environment, The American Journal of Occupational Therapy, Vol. 46, No. 5, May, 1992, pp. 434-443.

Gutkowski, S.; Ginath, Y.; Gurrmann, F., Improving Psychiatric Environments Through Minimal Architectural Change, Hospital and Community Psychiatry, Vol. 43, No. 9, Sept. , 1992, pp. 920-923.

Mallik, K.; Elder, G., Consumers Who Choose Use..., Proceedings, RESNA, 16th Annual Conference, June, 1993, pp. 39-40.

Mallik, K.; Stinson, D., Business and Rehabilitation: A Partnership on Work-Site Accommodations, Proceeding, RESNA, 17th Annual Conference, June, 1994, pp. 48.

Porter, D. Implementation of a Systems Approach to Supported Education at Four California Community College Model Service Sits, Psychosocial Rehabilitation Journal, Vol. 17, No. 1, July, 1993, pp. 171-187.

THE STAIR ASSISTtm SYSTEM - A CLINICAL TRIAL

John M. Medeiros, PT, Ph.D.
Pacific University, School of Physical Therapy
Forest Grove, OR 97116

ABSTRACT

A clinical study was undertaken to investigate the safety and efficacy of the newly developed Stair Assist. Eighty one subjects were tested. Subjects completed a questionnaire concerning medical diagnosis, assistive device use, frequency of falls, stair climbing ability and other indicators of functionality prior to stair walking. Subjects were then asked to walk up and down a flight of stairs without and with the Stair Assist. All subjects were filmed during stair walking trials and a standardized set of questions regarding ambulation without and with the Stair Assist was administered. The results of the study revealed that the Stair Assist was able to decrease the subject's fear of falling, lesson the physical difficulty of walking on stairs and reduce the fatigue, pain and discomfort that is frequently associated with stair walking in the person with a physical disability.

BACKGROUND

Both age-related declines in the sensory-motor system (1,2) and a wide range of injuries and diseases frequently limit stair use ability (3-5). A decreased ability to bear weight on the lower extremities resulting from structural damage of the skeletal system, muscle weakness or partial paralysis of the trunk or lower extremities or poor balance in the upright posture frequently make safe stair ambulation unattainable.

The current emphasis on controlling health care costs by enabling people to remain in their homes, or return to them sooner after hospitalization, strongly supports the natural desire of individuals to live independently and in the home of their choice. Thus, assistive devices are frequently needed to make stair ambulation safe.

RESEARCH QUESTION

For all but the truly non-ambulatory, a person's lower extremities can furnish the bulk of support and motion during level walking. What is needed is stability, and something to which weight can be transferred while staying in a properly aligned posture. Walkers often serve this function on level surfaces. What can provide this function on stairs? In order to answer this question, the use of the Stair Assist for individuals who have difficulty climbing stairs was investigated in a clinical trial.

EQUIPMENT

The Stair Assist is a battery-powered ambulation aid used to provide support or stability for a person as they walk up and down stairs. Users hold onto the Stair Assist power bar with their hands and they control the speed of movement of the bar with a finger switch. The power bar is driven up and down a steel guide rail system which is mounted on the wall.

SUBJECTS

Eighty one subjects with a wide range of stair climbing abilities were tested. The criteria for selection of subjects included home owners who were over 65 and children and adults who had difficulties with stairs or concerns such as fear of falling while ascending or descending stairs. Other factors considered in the selection process were that the subjects were oriented and lucid with respect to person, place, time and able to comprehend and follow instructions.

The 81 subjects ranged in age from 5 to 93 with a median age of 71 years. The subjects had 110 sets of stairs between them, 45% to the upstairs and 55% to the basement. Fifty six percent of the subjects had reported prior falls on stairs (27% more than once).

All subjects could take at least a few steps with or without the use of ambulatory aids such as walkers, crutches or canes. Twenty five percent of the subjects used an assistive device for ambulation. Forty nine of the subjects were women and 32 were men.

The most prevalent demographic subject data relative to diagnosis was as follows: arthritis (64%), respiratory conditions (27%), osteoporosis (19%), heart/circulatory disorders (16%), tendinitis (16%), diabetes (14%) and cataracts (14%). Other diagnoses included: stroke, multiple sclerosis, Parkinson's, muscular dystrophy and cerebral palsy.

The most predominant subjective symptoms reported by the subjects were as follows: stiffness (63%), knee pain (54%), fatigues easily (49%), shortness of breath (48%), back pain (47%), difficulty walking (47%), dizziness/balance problems (43%), stumbling (40%) and hip pain (38%). Other disabilities included: weakness, arm/hand pain, limited vision and general frailty.

Ninety six percent of all subjects reported specific problem with stair use. Areas of concern were as follows: fear of falling (64%), physically difficult (64%), fatigue (62%) and pain or discomfort (59%).

METHOD

Initially, subjects walked up and down a flight of stairs in their usual manner. Following this, subjects used the Stair Assist to walk up and down the flight of stairs. In addition to filming all subjects during stair ambulation with and without the Stair Assist, a standardized set of questions regarding efficacy, performance, features and ease of use regarding the Stair Assist was administered.

Observational gait analysis of the videotapes provided the framework for identifying specific gait deviations during stair walking. Questions regarding performance of the Stair Assist were evaluated on a 1 (poor) to 4 (very good) scale. Functional performance was assessed as a percentage of improvement felt when using the Stair Assist as compared to not using the device.

RESULTS

Review of the videotapes revealed that the Stair Assist aided in the maintenance of support of the head, arms and trunk against gravity. In addition, maintenance of upright posture and balance was significantly improved when subjects used the Stair Assist.

The Stair Assist was rated well above satisfactory regarding mechanical performance, features and ease of use. Ratings for solidness and overall performance approached a rating of 4. The Stair Assist appears to strike a balance among the often conflicting requirements of safety, comfort and ease of use.

Ninety six percent of the population who had expressed specific problems with stair use were asked to rate the Stair Assist in terms of its impact on fear of falling, physical difficulty, fatigue and pain or discomfort. A significant degree of improvement was reported for each category.

DISCUSSION

The results of this study indicated that the Stair Assist is able to decrease the subject's fear of falling, lessen the physical difficulty of walking on stairs and reduce the fatigue, pain and discomfort that is frequently associated with stair climbing in the person with a disability.

The reduction of the fear of falling when using the Stair Assist seems intuitively reasonable since the bar is directly in front of the subject when they ascend and descend stairs. It is reasonable to expect that this benefit will translate into an actual reduction in the incidence of falls on stairs.

With respect to a lessening of physical difficulty and fatigue, the Stair Assist provides optimal security, safety and function with the least expenditure of energy. The improved posture that the Stair Assist allows eliminates the twisting and pulling required by the upper extremity when the subject use a standard hand rail.

In view of the subjects ability to walk more symmetrically with the Stair Assist, it is not surprising that the degree of pain was lessened. Loads imposed upon joint structures of the back, hip, knee and ankle are significantly affected by the musculature acting around the joints. A more symmetrical gait pattern should result in a more efficient utilization of musculoskeletal structures.

REFERENCES

1. Kaplan FS, Nixon JE, Reits M, Rindfleish L, Tucker J: Age-related changes in proprioception and sensation in joint position. Acta Ortho Scand, 56:72-74, 1985.
2. James B, Parker AW: Electromyography of stair locomotion in elderly men and women. Electromyogr Clin Neurophysiol, 29:161-168, 1989.
3. Reddy HK, McElroy PA, Janicki S, Weber KT: Response in oxygen uptake and ventilation during stair climbing in patients with chronic heart failure. Am J Cardiol, 63:222- 225, 1989.
4. Olsen GN, Bolton JW, Weiman DS, Hornuno CA: Stair climbing as an exercise test to predict the postoperative complications of lung resection. Two years' experience. Chest, 99:587-590, 1991.
5. Mossberg KA, Linton KA, Friske K: Ankle-foot orthoses: effect on energy expenditure of gait in spastic diplegia children. Arch Phys Med Rehabil, 71:490-494, 1990.

John M. Medeiros, PT, Ph.D.
Pacific University
School of Physical Therapy
2043 College Way
Forest Grove, OR 97116
(503) 357-6151

VIDEOCONFERENCE TECHNOLOGY:
EXPLORING AN ALTERNATE SERVICE DELIVERY MODEL IN HEALTH CARE

Lilly Wong, M.Sc., S-LP(C) and Jacqueline Dupuis, M.Sc., S-LP(C)
Sunny Hill Health Centre for Children, Vancouver, Canada

ABSTRACT

As a tertiary health care agency providing specialized clinical services to children, aged 0-19 years, living in the province of British Columbia, we have recently begun investigating videoconference technology as a service delivery option. In October 1994, a videoconference trial was completed in which assessment services were provided to the family and community team members of a 30 month old child born prematurely with dystonic cerebral palsy. The goal of this assessment was to provide communication programming suggestions, taking into consideration motor function and vision issues. This poster will illustrate the videoconferencing technology used in our trial, and share an evaluation of the clinical efficiency and quality of the service that was provided. A cost comparison between outreach services and videoconferencing will be made. Also, technology options and future implications will be presented.

BACKGROUND

The goal of many community-based service delivery models for individuals with physical disabilities is to attempt to collaborate with as many members of the individual's team as possible. Outreach services have been an important option for achieving this goal. Service providers go to the community to assess the individual and, with input from family and team members, make recommendations on specific issues identified by the team. When outreach services are implemented over a large geographic area (e.g. a state or province), costs can be considerable. Costs generally include airfare, ground transportation, accommodations, meals, overtime, and salaries/benefits. Typically, funding limits the number and frequency of outreach visits within a given year. The physical demands of travelling are often an added stress to the service providers. Recent advances in technology may offer some alternate means to deliver services to clients at a lower cost overall.

Technology has given us many ways to interact with people irregardless of distance -- facsimile, modems, e-mail, bulletin boards, the Internet, teleconferencing, videoconferencing. Teleconferencing is already an accepted means for professionals and families to meet as a group without having to be physically in the same room. However, the absence of visual images makes the use of teleconferences less conducive to client assessments or consultations. Videoconferencing, on the other hand, offers both audio and visual modalities, and hence, more natural, interactive communication. Recent developments in both room-based, full motion videoconferencing and in desktop computer-based videoconferencing may offer cost-effective alternatives to outreach services.

OBJECTIVE

To determine if videoconferencing might be a cost-effective way to provide assessment or consultation services to children with physical disabilities, their families and community team members. To gain insight into the type and quality of service that could be potentially provided through videoconferencing technology.

METHOD

The technology used was room-based, full motion videoconferencing over the Ubiquity fiber-optic network. A large monitor was located at each site along with cameras - one at the host site, two at the remote site. The host site was the videoconference room at B.C. Tel Advanced Communications in Metro Vancouver, while the remote site was a meeting room at the Coast Hotel in Kelowna (400 km. from Vancouver). The fiber optics network produced visual images and audio transmission in real time. Duration of the assessment was approximately 1.25 hours and involved a total of nine participants plus two B.C.Tel staff (host site: two speech-language pathologists (S-LP), one occupational therapist (O.T.); remote site: child, mother, child care worker, and the community S-LP, O.T., and P.T. (physiotherapy)).

The purpose of the assessment was to assist the family and community team with strategies to develop communication skills in light of the client's (a 30 month old boy with dystonic cerebral palsy) severe physical disability. A videotape of the child was before the trial. At the videoconference, the community team and family were positioned on a floor mat with the client. One remote camera was hand-held at floor level, while another was set on a tripod to give a view of the room; both were operated by the technician. The host site controlled the video transmission. The remote team demonstrated how the client was typically positioned for communication and switch use. The consulting clinicians provided suggestions on how to best position and facilitate the child's responses.

An outreach visit occurred six weeks after the videoconference to ensure all questions from the family and team had been adequately answered. Feedback about the videoconference assessment was obtained immediately after the trial and during the outreach visit from the family and community team.

RESULTS

Based on the impressions made during the videoconference, the speech-language pathology consultant recommended the implementation of several eyegaze communication strategies. An eye gaze board was shipped to the community for a trial. Suggestions were made for further experimentation with visual fields as well as the size and colour of the symbols to be used. It was recommended that the team delay switch training until better body positioning and control could be achieved.

Six weeks following the videoconference, the child was seen on outreach. A speech-language pathologist and occupational therapist travelled to the Child Development Centre in Kelowna where the child received therapy services. The child, his day care worker, father, and community speech-language pathologist were present.

Activities conducted during the outreach visit confirmed initial recommendations regarding eyepointing, vision, and body positioning. The opportunity for the consultants to interact directly with the child, however, revealed a higher level of functioning than previously observed. A possible explanation was that there was a bias toward viewing the client as being less able to perform certain skills based on the limited number of activities observed during the videoconference. The benefits of being able to demonstrate intervention techniques with the child present and to model communication facilitation strategies with the caregivers were also underestimated.

DISCUSSION

From a clinical perspective, the participants appreciated the interactiveness of the videoconference experience. In particular, they liked the ability to immediately respond to questions and to modify the position of the child or objects as needed. The two cameras allowed for close-up and room views, which enabled the consultants to feel close to the action. Because activities occurred in real time, there were no distracting delays in transmission of video or audio data. The ability of the technology to capture movements (e.g. eye gaze) fluidly was critical to obtaining accurate information about the client's abilities and potential skills.

As an initial experience, videoconferencing appeared to be an adequate means of exchanging information about the client and of giving preliminary recommendations. However, information gained from the subsequent outreach visit revealed the necessity of seeing the client in person. Further investigation will be needed to determine what types of assessments would best be done using videoconferencing. In some cases, the consultants may need to interact with or hold the child in order to make appropriate clinical recommendations. If equipment will be used for the assessment, the community team would have to have access to it and become familiar with it prior to the assessment. Participants would also need to learn the best ways to position themselves and the client in front of the cameras. The opportunity to view the videotape of the client, as part of the pre-assessment planning, will continue to be valuable for the consultants. It will also be important for the host and remote sites to have dedicated rooms set up with furniture and equipment appropriate to the clients being served. This would lessen the time and effort needed for each assessment.

In comparing costs between outreach and videoconference services, the latter can be substantially less expensive, when initial technical installation costs are excluded. For this trial, the two site exchange over the fiber-optic network was approximately one-quarter of the cost of sending three consultants to Kelowna by air for the day, including meals and overtime. Also, consultants did not have to contend with the physical demands of travelling.

The overall costs of offering videoconferencing as a means of delivering services must be considered. Room-based full motion videoconferencing systems offer real time but require expensive fiber-optic cable to transmit video and audio data without delays. While new facilities are now being constructed with videoconferencing in mind, existing organizations would need to raise sufficient funds to cover installation of fiber optics. One idea that is growing in popularity is for agencies to team up and share both implementation and usage costs. In British Columbia, three teaching hospitals are using videoconferencing for medical rounds. As the supervising physician discusses patients with residents at the host site, residents at two remote sites are watching and interacting via monitors. Desktop computer-based videoconferencing systems such as PictureTel's Live PCS 100 or Northern Telecom's Visit have emerged with advent of video capabilities on personal computers. Desktop systems send video and audio images over high-speed telephone lines, using compression technology to achieve close to realtime images. Whether the compressed video images produced are adequate for assessments and consultations in which the client must make specific movements, has yet to be determined by the authors. Typically, the video image is smaller, colour resolution appears grainier, and fewer frames can be transmitted per second (5). Also, while desktop video systems are less costly, there are currently no industry standards for compression and transmission of video images over phone lines. This means that two agencies would need to use exactly the same system before video communication would be possible. With the lightning speed at which technology is moving, health care facilities would need to anticipate spending additional dollars on upgrading their desktop videoconferencing systems over time.

Cost effectiveness relates to the value of the outcome compared to the expenditure (3). Initial start-up costs will be considerable for either room-based or desktop video systems, but there is not doubt that videoconferencing has a role in the delivery of health-related services (4). Videoconferencing will not eliminate the need for specialists to see clients in person, however, it offers health care agencies a cost-effective alternative to both on-site and outreach assessments, while meeting the needs of families and communities.

REFERENCES

1. Eyler, S., M.S., OTR. Video outreach to rural Vermonters. Presented at Seating & Mobility Conference, Boston, July '94.
2. MacKay, Ian R.A. (1994) Interactive videoconferencing in the education of speech-language pathologists. Communique, 8:2, 34-38.
3. Warren, C. Gerald. (1993). Cost effectiveness and efficiency in assistive technology service delivery. Assistive Technology, 5:2, 61-65, RESNA.
4. Inkster, Mark. (1994) Medical multimedia applications. Healthcare Computing & Communications Canada, 8:3, 68-69, April.
5. Reinhardt, Andy. (1993) Video Conquers the Desktop. BYTE, 18:10, 64-80, Sept.

Lilly Wong,
Communication Development Department,
Sunny Hill Health Centre for Children
3644 Slocan Street
Vancouver, B.C., Canada
V5M 3E8
Phone (604) 436-6514
Fax (604) 436-1743
Internet lillyw@sunny.wimsey.com

RESEARCH IN LEISURE AND THE FAMILY

A. Meghan O'Donnell
Chatham College, Occupational Therapy Department
Pittsburgh, Pennsylvania U.S.A.

ABSTRACT

Participating in leisure activities reduces tension and is a successful coping mechanism used by individuals and families to adapt to life transitions. Assistive technology may help create opportunities for leisure activities and help maintain family cohesiveness. There is not enough research that examines the relationship between family life, leisure, and assistive technology. The goal of this paper is to examine the role of assistive technology in creating opportunities for family-oriented activities. This paper will discuss the theoretical framework that examines the process of family adaptation. It will also outline potential research themes that would further highlight this relationship. Areas requiring further research will be highlighted and recommendations for methodology will be presented.

BACKGROUND

Participating in leisure activities provides an escape from the stresses of everyday life. Studies indicate that this escape reduces tension and is a successful coping mechanism used by both individuals and families (Sneegas, 1988). A study by Steinkamp and Kelly (1986) indicated that participating in leisure activities contributed to successful adjustments to life transitions. One of the life transitions examined was the family's adaptation to a member's disability (Hughes and Keller, 1992). It was found that reducing tension, adapting to changes and coping with problems were all crucial elements in maintaining family health. Assistive technology may help create opportunities to engage in leisure activity by decreasing the time constraints of daily living tasks, and increasing access to various leisure activities for the disabled.

PROBLEM

Although research regarding the importance of leisure activities is beginning to surface,the problem is that there is a shortage of research that examines the impact of assistive technology on family health for people with disabilities. The goals of the paper are:

1. To examine the potential effect of assistive technology on opportunities for family-oriented leisure activities.
2. Describe its relationship to a family's adaptation to disability.
3. Outline potential research themes that would further highlight this relationship.

These goals will be realized by presenting a theoretical model of family adaptations and discussing current research trends in the leisure field.

APPROACH

In order to understand how assistive technology can help a family adapt to a disability, the process of adaptation must be examined. The resiliency model discussed here explains the process a family faces when a member becomes disabled (Kosciulek, McCubbin, and McCubbin, 1992). The model is characterized as having two phases of reorganization. They are the adjustment and adaptation phases. The adjustment phase is characterized by a family's attempt to maintain patterns of interactions and rules that have been established to guide daily activity. Assistive technology in this phase can help decrease the amount of time that families will need to complete daily activities.The adaptation phase is the family's attempt to restore stability in the face oF excessive demands and depleted resources. According to Jackson, (1987), these factors may serve as constraints to a family participating in leisure activities as a unit. A constraint is defined as a real or perceived barrier to fulfilling a leisure need. Assistive technology can eliminate these real and/or perceived barriers by helping an individual with a disability achieve a high level of independence and engage in various leisure activities. This decreased the number of demands placed on the family, which may be the *real* barriers. This may also help foster the feeling of accomplishment and success needed to overcome the perceived barriers to leisure pursuits.

IMPLICATIONS AND DISCUSSION

Clearly, more research on the impact that assistive technology has on a family's leisure lifestyle is needed. Some themes and methods of research that would greatly increase our understanding of the disabled and their families leisure lifestyle are

1. Time use studies that identify the strength of the relationship between the use of assistive technology and the amount of perceived leisure time available.
2. Studies that examine the correlation between the level of family stress and the amount of family leisure time.
3. Studies that measure the family's quality of life when the disabled member has access to assistive technology.
4. Qualitative research that examines the role of assistive technology that is used by all members of the family in promoting leisure time.

A theoretical framework such as the one outlined here is required to realize this research goals. Futhermore, research models that reflect a rigorous methodology will provide the data necessary to understand the relationship between assistive technology, leisure and family life.

REFERENCES

Hughes, S., and Keller, J. (1992). Leisure Education: A Coping Strategy For Families. *Journal of Gerontological Social Work*, 19;115-128.

Jackson, E.L. (1987). Leisure Constraints: A Survey of Past Research. *Leisure Sciences*, p. 203-225.

Kelly, J.R., and Stienkamp, M.W. (1986). Later Life Leisure: How They Play in Peoria. *The Gerontologist*, 26, 531-537.

Kosciulek, J., McCubbin, M., and McCubbin, H. (1993). A Theoretical Framework for Family Adaptation to Head Injury. *Journal of Rehabilitation*, 59, 40-46.

Sneegas, J. (1988). *The Role of Leisure for Caregivers of Individuals with Alzheimer's Disease.* Paper presented at the meeting of the Annual National Recreation and Park Association on Leisure Research, Indianapolis, IN.

A. Meghan O'Donnell
5721 Pebble Creek Court
Apt. 2401
Bethel Park, PA 15102

FROM HOSPITAL TO COMMUNITY: OPPORTUNITIES FOR MEANINGFUL ACTIVITY THROUGH THE DEVELOPMENT OF RECREATION OUTREACH NETWORKS

Renee F. Lyons
School of Recreation, Physical and Health Education
Dalhousie University
Halifax, Nova Scotia, Canada

ABSTRACT

This paper argues for the development of a network system of outreach recreation services for persons with a disability. Quality of life studies show that social isolation and inactivity, fostered by a lack of meaningful work and leisure opportunities, are salient features of the lives of many persons with a disability in Canada and the United States. Outreach recreation services can play a central role in addressing these problems, not only for persons with little hope for paid employment, but for persons whose disabilities produce major constraints to leisure with family and friends. The primary components for dynamic recreation outreach networks currently exist in many regions. This paper provides guidance on how these networks can be developed with insights from the Nova Scotia experience.

INTRODUCTION

Over the past fifteen years, there has been considerable effort devoted to examining the recreation and leisure needs of persons with disabilities in rural and urban Canada (e.g. Environics 1989; Lyons, 1986). Canadians have also initiated many types of recreation strategies to facilitate involvement in meaningful activity. Several municipal recreation departments have developed creative strategies to facilitate leisure experiences including leisure buddies, leisure education and counseling methods, access policies and home-based recreation services (Lyons, 1991a). However, public recreation services probably represent one of the most underutilized possibilities for social integration and rewarding activity for persons with disabilities (Hutchison & McGill, 1992). Persons in rehabilitation hospital may be encouraged by in-house recreation opportunities and assurances by staff that many opportunities exist for meaningful activity in their community. This optimism may rapidly decline in the transition from hospital to home life due to a paucity of transitional services.

Although the term, outreach, has not normally been applied to such services, the potential development of networks of outreach recreation services in Canada would provide substantial benefits to persons with disabilities. The presence of the community recreation service system in Canada, the presence of recreation staff persons in most regional rehabilitation centers, the knowledge currently available on the delivery of recreational services to persons with a disability suggest that the time is right for giving serious consideration to such networks.

THE PROBLEM

In simple terms, for many persons with disabilities, there is an overabundance of discretionary time with little of perceived value to do during that time. Numerous Canadian and American studies, conducted over the past ten years by government, voluntary agencies, and researchers, using varying methodologies and samples have documented the presence of high levels of depression, inactivity, social isolation, suicide, and a lack of hope and meaning in their lives (e.g., Environics Research Group Ltd., 1989; Kinney & Coyle, 1989; Lyons, 1987, 1991b).

RECREATION'S ROLE

To examine the role recreation services can perform in addressing the issues of social isolation and inactivity, two questions must be addressed:

(1) In a world which values paid work and relegates other forms of activity, including homemaking, to secondary status, is there a salient role for recreation services for persons with a disability? In a work-oriented society, people undervalue leisure and recreation and miss its potential for increasing well-being (Neulinger, 1990). It has been suggested by Argyle (1992) that leisure with work-like qualities seems more socially acceptable, such as leisure that is serious, is of use to others, meets high standards, uses skill and leads to recognition of excellence. To a great extent, people depend on involvement in recreation and leisure activity for pleasure, for competence development, the fostering of close relationships, relaxation, creativity, mental and physical health, and to add meaning and purpose to life (Ankebrand, 1972; Argyle, 1992; Rook, 1987). For a comprehensive benefit analysis of recreation involvement by persons with disabilities, see Coyle, Kinney, Riley, & Shank, 1991.)

(2) What needs changing - the individual or the social context? There are often major psycho-

social and economic constraints to overcome in accessing community leisure opportunities for persons with disabilities. Activity adjustment to disability is influenced by individual factors such as pre-onset lifestyle, psychological state, sociodemographics, and cognitions about activity and coping style; illness/disability factors such as diagnosis and illness activity, functional ability, lifestyle changes, and support needs; and contextual factors such as the availability of social support, and meaningful recreation opportunities. Thus, recreation services must approach the absence of meaningful activity through both micro and macro strategies, the former involving development of recreation services using an individualized approach, and the latter, a social change approach that works toward more accepting, supportive communities.

OUTREACH RECREATION OPPORTUNITIES

The components are in place to structure networks of outreach recreation services.

(1) **Municipal recreation services.** There are over 1000 municipal recreation commissions in Canada and most communities with a population base of over 1500 have a recreation staff person. Small communities typically possess a volunteer recreation committee or commission, whose responsibility it is to contribute to the quality of life of a community by providing recreation programs, services, and facilities.

(2) **Training in recreation for persons with a disability/therapeutic recreation.** With respect to the ability of municipal recreation departments to provide outreach recreation services, recreation education programs in Canada usually require coursework on disability, and several universities (e.g., University of Waterloo, Dalhousie University, Brock University) offer a specialty in therapeutic recreation. There is also journals on leisure and disability and several texts (e.g. Hutchison & McGill, 1992) on community recreation services for persons with disabilities.

(3) **Assessment and intervention strategies.** There are now a considerable number of leisure assessment instruments (burlingame & Blaschko, 1991) for the measurement of leisure attitudes, satisfaction, needs, interests, constraints and competencies. Advances have been made in facilitating activity adjustment to particular health problems such as cardiac conditions, asthma, diabetes, and spinal injury. There is knowledge of how to adapt specific activities and inspiring role models of successful work and leisure adjustment, despite severe disability. Community and therapeutic recreation services have evolved to provide a broad range of facilitative services including leisure resource information, leisure counseling, leisure buddies, increased physical accessibility of facilities, methods to identify constituents' needs and wants, and the use of leisure as an individual and social change mechanism.

(4) **Many rehabilitation centers have recreation specialists**. Recreation therapists can be utilized as leisure education consultants and referral agents for their patients who are returning home and can collaborate with municipal recreation staff to ensure that local recreation opportunities are provided.

(5) **Federal and provincial governments** can provide support for demonstration research projects on network procedures, needs assessments and outcome studies, opportunities for sharing strategies across the country, and in-service training opportunities to increase competence in community service delivery.

THE NOVA SCOTIA EXPERIENCE

The Province of Nova Scotia is currently embarking on the establishment of a recreation outreach network. The strategies being developed are person and system focused. They include a provincial toll-free consumer line, standardized assessment and referral form, a human and recreation resource data base, and a provincial outreach network. These strategies have been based on almost twenty years of experimentation with different outreach efforts. In September of 1977, the Recreation Council for the Disabled in Nova Scotia initiated a recreation outreach program for persons with disabilities living in rural Nova Scotia. The program involved the provision of a facilitator in three regions of the Province to bridge the gap between the consumer and the community leisure opportunities. Often the first home visits by a leisure facilitator resulted in addressing very basic rehabilitation issues. For instance, an adult with spinal injury had not been out of his house for two years because the house was inaccessible; his wheelchair required repairs.

After two years, the facilitator program was evaluated and numerous individual and community outcomes had resulted. Although seemingly costly, each individual case that was addressed had significant impact on many others. Addressing the physical accessibility issues of one physically disabled person resulted in many facilities becoming accessible for others with mobility and sensory problems. Sports and recreation clubs which addressed issues such as registration fees or the need for adapted equipment generalized their new competencies to other situations.

The dark side of this project and many others that had been established across Canada was that, as true change in the system was becoming apparent, the federal government decided that recreation was a provincial responsibility. It quickly withdrew financial support, in the early eighties, from most of the federally funded projects. As a consequence, most provincial governments were not prepared to supplement their original financial commitments to fill the federal funding void. Although many provinces are currently involved in some initiatives for persons with a disability, they have been considerably scaled down. The new Nova Scotia initiative builds upon these political, financial and service experiences.

REFERENCES

Ankenbrand, L.J. (1972). The self concept of students physically handicapped and non-handicapped related to participation in an individual sport. University of Missouri, Doctoral dissertation.

Argyle, M. (1992). The social psychology of everyday life. London: Routledge.

burlingame, J., & Blaschko, T.M. (1990). Assessment tools for recreation therapy, Red Book #1, Seattle: Idyl Arbor, Inc.

Coyle, C.P., Kinney, W.B., Riley, B., & Shank, J.W. (1991). Benefits of Therapeutic Recreation: A consensus view. Philadelphia: Temple University.

Environics Research Group Ltd. (1989). The needs and attitudes of Disabled Ontarians. Office for Disabled Persons, Prov. of Ontario.

Hutchison, P., & McGill, J. (1992). Leisure, integration, and community. Ontario: Leisurability Pub. Ltd.

Kinney, T., & Coyle, K. (1989). Predictors of quality of life among physical disabled adults. Research report, Philadelphia:Temple University.

Lyons, R. (1986). The impact of chronic illness on activity patterns and friendships. Research report to Fitness Canada, Halifax: Dalhousie University.

Lyons, R. (1987). Leisure adjustment to chronic illness and disability. Journal of Leisurability, 14 (2), 4-9.

Lyons, R. (1991a). Municipal government policy guidelines: Recreation services for persons with a disability. Canadian Parks and Recreation Association, Ottawa.

Lyons, R. (1991b). The effects of acquired illness and disability on friendships. In W.H. Jones and D. Perlman (Eds.) Advances in personal relationships, Vol. 3. London: J. Kingsley Pub.

Neulinger, J. (1990). The road to eden after all: A human metamorphisis. The Netherlands: Giordano Bruno Culemborg.

Rook, K. (1987). Social support versus companionship: Effects on life stress, loneliness, and evaluations by others. Journal of Personality and Social Psychology, 47, 1132-1147.

ACKNOWLEDGEMENTS

Funding and other supports for these initiatives has been obtained from Fitness Canada, Province of Nova Scotia, and the Recreation Council on Disability in Nova Scotia.

Renee F. Lyons, Ph.D.
Associate Professor
School of Recreation, Physical and Health Education
Dalhousie University
Halifax, N.S., Canada B3H 3J5
(902) 494-1152 rlyons@ac.dal.ca

ACCESSIBLE KAYAKING-THE NEXT GENERATION: TO PADDLE LIKE NO ONE HAS PADDLED BEFORE!

Douglas R. Nichols
University of Victoria/Recreation Integration Victoria
Victoria, B.C. Canada

ABSTRACT

Ocean kayak touring as a culturally normative and societally esteemed physical activity has the potential to become integrated, normalized recreational venue for a number of individuals living with disabilities. access to such an opportunity depends upon a number of equipment adaptations facilitating a safe, challenging and enjoyable experience. Specific adaptations involve cockpit alteration for entry and fail-safe wet exit, seating, floatation and steering.

OBJECTIVE

For the past four years the Leisure Service Administration program at the University of Victoria, in partnership with Recreation Integration Victoria, a consortium of local municipal recreation departments, has been involved with a project designed to introduce kayaking as a lifetime recreational activity to individuals living with lower body impairments. The project has focused on the development of equipment adaptations in order to provide a safe yet challenging outdoor adventure opportunity.

BACKGROUND

Although the activity of kayaking (both competitive racing and recreational touring) would seem to provide quite an appropriate venue for the participation of individuals living with lower body impairments in a culturally normative and socially esteemed outdoor recreational activity, a literature review uncovered relatively few useful historic, programmatic or developmental resources. Some anecdotal accounts of various kayak excursions involving people living with disabilities exist (Lynch, 1972; Leisheiser & Levy, 1983; Ciotto, 1980; Jacobs,1985) as does limited information describing organizations offering training and expedition opportunities (Cando, Toronto; Nantahala, North Carolina; Challenge Alaska, Anchorage). Information regarding equipment adaptations specific to kayaking is even more sparse (Galland,1981), and information dealing with physical and/or medical considerations is available only as it relates to wheelchair athletes and other generic wheelchair users (Martinez,1989; Garber, 1985). The existence of this rather limited resource base leads to two possible conclusions; (1) either very little is occurring to encourage those living with lower body impairments to become involved in an activity which has the potential to be an extremely valuable outdoor pursuit as part of an individual's competitive and/or recreational activity inventory or (2) few are undertaking the task of reporting attempts at the provision of such an opportunity.

Given this lack of documentation but in the belief that the activity of kayaking was, on the whole, quite suitable as a normalized competitive and recreational opportunity particularly well suited to individuals living with lower body impairments, a British Columbia Games Legacy Development Fund grant was secured which provided sufficient funds for the construction of an adapted kayak.

APPROACH

The concept of undertaking a project with this particular focus was initiated by the Disabled Sports Committee of the 1988 British Columbia Summer Games using existing participatory opportunities as a catalyst to increased participation for individuals living with disabilities in terms of both quantity and quality of experience. Slalom kayaking was

69

seen as one of the very few competitive venues where even close to a "level playing field" for both disabled athletes and their able-bodied peers was possible. However, after surveying local wheelchair users and advocate associations it became apparent that there was far more demand for kayaking as a recreational as opposed to a competitive activity. With this in mind a group of interested paddlers, designers and instructors began to construct and test equipment adaptations which would provide as full access as possible to wheelchair users into the field of ocean kayaking, often called kayak touring.

DISCUSSION

Adaptations to the structure of the kayak itself to facilitate safe yet challenging use of the vehicle as a recreational resource concentrated on four areas: cockpit, seating, flotation and steering.

Cockpit

In order to facilitate convenient and safe entry to and exit of the kayak, considerable adaptation of the cockpit proved necessary. Any vehicle used for recreational kayaking must allow for ease of entry into the vehicle, relative stability while pitching side-to-side under sometimes adverse weather conditions and quick and fail-safe exit both on top of and underneath the water.. To accommodate individuals living with lower body impairments, where both entry into and exit from the vehicle are somewhat problematic due to unresponsive and often stiff lower appendages, a cockpit joined by a removable "carapace" was designed. This design feature allows for upper hull removal both on top of and underneath the water for safe exit. At the same time, the carapace is joined to the rest of the hull tightly enough so that gravity and body and/or water pressure alone will not displace the apparatus. The carapace is linked to the hull through the use of a velcro strapping and stud and sleeve joint system and made water-worthy with the addition of a rubber gasket. Field testing has proven the system to be quite manageable, although repetitive movement training is necessary in order to ensure safe and efficient underwater ("wet") exit.

Seating

The adapted kayak has been fitted with an ocean touring seat which is positioned directly on the floor of the vehicle. It is slightly canted to the stern to force a seated position where the upper legs are slightly elevated. Often a 4"-5" piece of rolled ensolite is placed just below the knee to ensure proper bend. This position assists both balance and comfort. Flexible, removable pads are placed along side of the seat to permit the paddler security from sliding around on the seat yet allow for safe exit.

Flotation

Flotation buoys, attached to opposite ends of two telescoping arms, allowed variable external flotation to be applied on an individual "as needed" basis. This makes a normal single hulled kayak into a sort of trimaran, in effect a triple hulled kayak or "triak". At full extension this flotation kit makes the boat virtually untippable and therefore a perfectly adapted training vehicle useful in introducing absolute novices, particularly those with severe balance or muscular-skeletal difficulties to the independent activity of kayaking in complete safety. These "training wheels" have the distinct advantage of facilitating progressively less dependence upon the external flotation by simply positioning the buoy closer to the kayak hull. It is important to note that some individuals might always need the full additional flotation provided by this adaptation while others, through skill development and experience will outgrow this compensatory devise relatively rapidly. An additional beauty of such a devise is that it can be made adaptable to fit any "off of the rack" kayak either commercially available or home-made.

Steering

A touring kayak is normally directed through one of two standard methods; (1) a foot pedal controlled rudder system or (2) hull design which permits the entire kayak to act as a keeled vehicle. Although the second of these two has been used by manufacturers in the United Kingdom for many years, the level of paddling skill necessary to maneuver such a kayak under unstable weather conditions, or by a paddler with less than superb balance makes this alternative unsuitable for most paddlers with a disability. Using a British Columbia Student Design Challenge grant and after much experimentation we have designed, produced and successfully field tested two steering mechanisms which will allow paddlers to control the direction of their kayak using the standard (although adapted) rudder system. Our (1) sip and puff and (2) remote control steering mechanisms use a small battery operated

70

motor, completely enclosed in a water-tight container, to move the rudder at the paddlers discretion. The sip and puff system uses the normal two air pressure controls. The motor and battery are stored in the stern compartment of the kayak and take up less space that a camping cook kit. The only visible alteration to the kayak is the air tube which runs out of the back of the cockpit and on to a head set. The remote control system uses a transmitter located in the paddle and two recessed buttons which control the left and right movement of the rudder. These buttons are mounted using extra strength velcro and therefore can be moved to the hand grip position of each individual paddler. We are presently in the process of installing a solar array which will deliver energy for both immediate operation and "dark day" storage.

Ocean kayak touring as a culturally normative and societally esteemed physical activity has the potential to become integrated, normalized recreational venue for a number of individuals living with disabilities, particularly those living with lower body impairments and balance difficulties. Fortunately it can be accomplished on any relatively open body of water, an actual ocean is nice but not necessary! It is an activity which has not been stereotyped by society as one "appropriate for" people with disabilities. It is a "visually normalized" activity, where the paddler with a lower body disability appears visually identical to his or her paddling partners. It is an activity where the major piece of equipment used is a vehicle in which *all* participants are seated, creating little or no disadvantage for the wheelchair user. The kayak is a vehicle of *choice*, a universally accepted piece of recreational transport equipment. And finally, environmental barriers which are encountered during a paddling expedition are equally experienced by all kayakers, not just those with disabilities. We believe that the adaptations developed through the partnership of the University of Victoria and Recreation Integration Victoria will lead to fully accessible paddling opportunities for many individuals living with disabilities.

References

Cando Kayak Club. (no date). Information brochure.

Ciotto, R. (1980). Kayak: An accessible alternative on the boating scene. *Paraplegia News*, 33(5).

Galland, J.H. (1981). *An introduction to kayaking for persons with disabilities*. Loretto, Minn.: Vinland National Centre.

Garber, S. (1985). Wheelchair cushions for spinal cord-injured individuals. *The American Journal of Occupational Therapy*, 39(11).

Jacobs, S. (1985). Frolic under a midnight sun. *Sports 'n spokes*, 9(5).

Leisheiser, B. & Levy, R. (1983). Canoeing: A valuable experience. *Sports 'n spokes*, 9(4).

Lynch, W.J. (1972). Canoeing for recreation and rehabilitation. *Parks and Recreation*, 7(7).

Martinez, S. (1989). Medical concerns among wheelchair road racers. *The Physician and Sportsmedicine*, 17(2).

Douglas R. Nichols, Ph.D.
School of Physical Education
University of Victoria
P.O.Box 3015
Victoria, B.C. Canada
V8W 3P1

AN ANALYSIS OF ONE REHABILITATION ENGINEER'S WORK CONSIDERING JOB ACCOMMODATION COSTS AND CONSUMERS SERVED

Paul J. Schwartz
Center for Rehabilitation Technology
University of Wisconsin-Stout

Abstract

Many surveys of the cost of job accommodations thus far have not included the cost of the assessment required to determine the appropriate accommodation. This study analyzes the work of one rehabilitation engineer, looking at assessments performed from 1992 through 1994. The average cost of an assessment was $262. If driving was required, the average cost of the drive time was $216. Back injuries (23%) and upper extremity cumulative trauma disorders (23%) accounted for almost half of the individuals served. The average cost of an accommodation was $432. Custom work was performed in twelve percent of the implementations. One-third of the recommended accommodations were not implemented. The most common reason for non-implementation was the lack of employment.

Background

With the passage of the Americans with Disabilities Act, United Cerebral Palsy has published national statistics on the cost of implementing job accommodations. (UCPA,92,93) However, these figures have not included the cost of the assessment. Rearranging a workstation, a footrest and a copyholder may only cost sixty dollars, but it may have taken three hours of professional time to figure this out.

RESNA is now trying to figure out the true cost of implementing job accommodations, including assessment costs. RESNA has planned a special session for this conference, RESNA 1995, to discuss this issue. RESNA has sent job accommodation special interest group members surveys to detail assessments and their accompanying costs (Hedman,94). The data from the survey will come from a variety of service delivery models, including: hospitals, universities, vocational rehabilitation agencies and private consultants. This information is helpful for a general national view of implementation costs.

Together with this national study, I thought it would be useful to look at a "snapshot" of one rehabilitation engineer's work at one center. Costs, hourly rates and numbers of individuals served are common conversational fodder at RESNA conferences (what an exciting group we are). However, as a fee-for-service provider, it is often difficult to take the time to do a long term study of services.

Objective

The objective of this paper is analyze the service delivery work performed by a rehabilitation engineer, with respect to assessment costs, accommodation costs and individuals served.

Method

Service Delivery Model

I work for a rehabilitation technology facility housed in a university. Our center generates most of its service delivery income on a case by case basis. The charge for an assessment is determined per case, based on an hourly rate. Our current cost per hour is seventy-three dollars per hour, including driving time. Custom work is performed at the shop in our facility at an hourly fee of thirty dollars per hour.

Typically, I will perform an initial assessment and write a report listing recommendations. Implementation of recommendations is performed if requested. A feedback form is sent to the purchaser of service and the consumer involved. Follow-up is performed on an as needed basis.

Research Approach

All my files from 1992 through 1994 were pulled and reviewed. Any "dead" files, industrial ergonomic analyses or training files were not included. Case number, purchaser, assessment cost, drive cost, implementation cost and non-implementation reasons was entered on a spreadsheet for each case. Statistical analysis was performed with this data. Some estimates of product costs were made when it was known that a type of product was purchased, but not a specific model. Reasons for non-implementation are my opinions based on feedback and review of my casenotes.

Results

An average of fifty assessments were performed in each year of the study. The mean cost of an assessment was $262 (n=150,SD=185). If driving was required for the assessment, the average cost for the drive time was $216 (SD=146). The average cost of implemented products was $432. Figure 1 shows the cost of products implemented. The most commonly recommended item installed was an office chair (26% of all implementations), followed by office ergonomic products, such as footrests and copyholders. Custom work was performed on twelve percent of all implementations. The most common custom work performed was modifying existing products to fit an individual, such as raising a workstation. Figure 2 shows the types of disabilities served. Back pain and upper extremity cumulative trauma disorders (UECTD) accounted for almost half of the individuals served. The purchaser of service is shown in Figure 3. Sixty-seven percent of the assessments resulted in implementations. The reasons for non-implementation are shown in Figure 4.

Fig. 1. Cost of Product

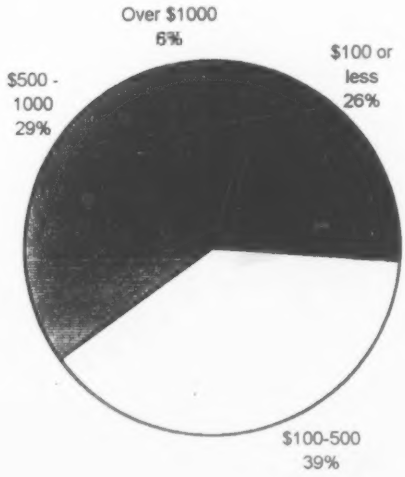


Fig. 2. Disability Types Served

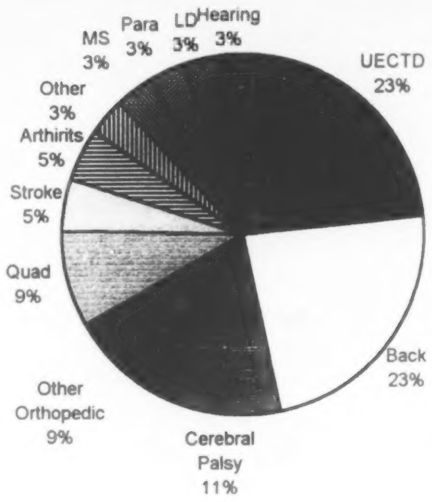
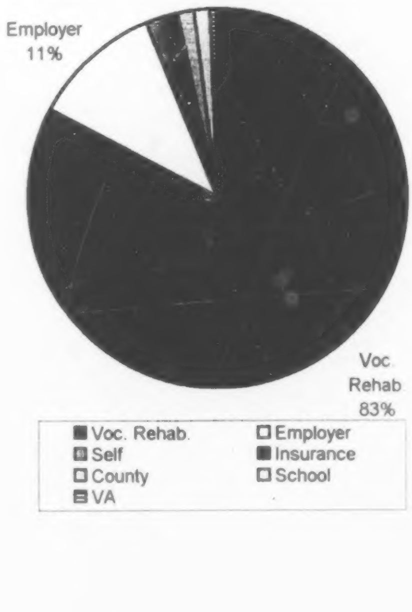
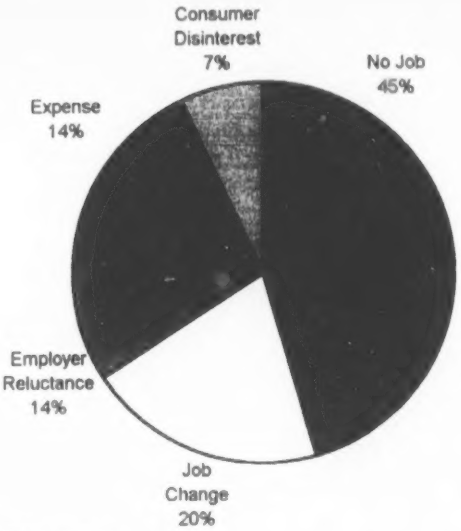


Fig. 3. Purchaser of Service



BEST COPY AVAILABLE

Fig. 4. Reason for Non-implementation



Discussion

The cost of implementation including assessment time appears to be within the spirit of "reasonable accommodations" and are in line with previous findings of accommodation costs. According to both UCPA reports, the cost of an accommodation is less than $500.00. This matches with the results in my analysis, not including assessment time.

Although much of the pride and enjoyment in rehabilitation engineering comes from design, the results clearly show that this is a small part of my work. This may be due to the individuals served and my style of work. This figure is likely to vary widely.

Too much revenue is generated from one source, vocational rehabilitation. Considering possible cutbacks in funding for vocational rehabilitation, it seems clear that other revenue sources most be generated to ensure survival of our center. Disabilities caused by cumulative trauma is a large part of my work. Therefore, ergonomic intervention prior to injury could be a possible area to focus on for additional revenue sources.

I believe that direct consumer services is an important component of a rehabilitation facility. However, generating funding from these sources is not enough to cover most rehabilitation engineers salaries completely. Other areas where rehabilitation engineering services could be used should be explored.

References

UCPA (United Cerebral Palsy Association), ADA Employment Report Card on America--Snapshot of American Business, July 21, 1992, Washington, DC.

UCPA (United Cerebral Palsy Association), 1993 ADA Report Card on America, August, 1993, Washington, DC.

Hedman, G., letter to RESNA SIG-14 Members, December 15, 1994, RESNA, Arlington, VA.

Paul J. Schwartz, M.S.I.E.
Rehabilitation Engineer
Center for Rehabilitation Technology
University of Wisconsin-Stout
(715) 232-2248

BEST COPY AVAILABLE

A SYSTEMATIC INTERDISCIPLINARY ASSESSMENT MODEL

Beverly K. Bain
New York University, Department of Occupational Therapy
New York, NY U.S.A.

Abstract

Assistive technology (AT) devices and services are considered as a synergistic system consisting of: (1) the user's needs and abilities, (2) the tasks s/he wishes to accomplish, (3) all possible environments where the consumer will use the device(s), and (4) possible devices that can successfully perform the desired task(s). A systematic, interdisciplinary assessment is critical to insure that the consumer is best served, that devices are fully used, and that funding is appropriately spent. A problem solving approach is outlined, including the collaborative efforts of interdisciplinary team members with the consumer and careprovider being the essential link in the total process.

Background

Today, there are many factors which warrant a systematic, holistic assessment prior to the selection of any AT services or devices, including: the proliferation of available assistive technology devices that can enhance the functional independence of persons with disabilities, the recent legislation that is providing more accessible environments, and the cost of devices and fees for services that are escalating while funding is diminishing. Yet the literature reports that many AT devices are underused or abandoned (Batavia & Hammer, 1990; Brooks & Hoyer, 1989; and Phillips, 1992). Reasons frequently cited include: (1) a lack of systematic holistic assessments in which the consumer is a contributing member on the assessment team, (2) the selection of devices lacks the collaborative effort of an interdisciplinary team, (3) the attitudes towards AT by consumers and society are not evaluated, and (4) training and follow-up services are not provided (Bain, 1993, 1994; Batavia, Dillard, & Phillips, 1992; Geiger, 1990; Scherer, 1989, 1991; and Smith, 1988).

Statement of the Problem

A systematic interdisciplinary assessment approach could lead to enhancing the successful use of AT devices by consumers, to accomplish more tasks in various environments. Currently, assistive technology service delivery is too complex to simply match the consumer's physical abilities with the newest device. A holistic evaluation of the consumer, present and future environment where the device(s) will be used and all the tasks that the consumer wants to accomplish must be given equal attention. For, in an effective and efficient AT system, each part is interdependent and interrelated.

Approach/Method

The proposed interdisciplinary assessment approach model consists of nine steps. In each step, the consumer and/or the careprovider must participate, but interdisciplinary assessment members or consultants may deviate according to the delivery system. The order of the steps may vary or several steps may be accomplished currently, but each step MUST be considered.

Step 1. Identification of the task(s) the consumer wishes to perform. General categories are manipulative or tasks requiring dexterity, communication tasks both written and verbal, and mobility. Identification must be made by the consumer and careprovider with collaboration of the total team.

Step 2. Identification of the user's physical, psychosocial and cognitive abilities by occupational and/or physical therapists, speech pathologists, social workers, teachers, vocational counselors, and seating specialists as required. Standard and nonstandard tests should be completed with results reported to the total team.

Step 3. Identification of possible AT devices characteristics including: the input method, the processing or throughput means, the output, and the feedback. The other pertinent factors are the functional performance, safety, reliability, affordability, and portability. Both "high" and "low" technological devices should be evaluated by rehabilitation engineers, occupational therapists, vendors and/or manufactors, and many times third party payors.

Step 4. Identification of all present and future environments where the AT will be used including bed, chair, home, school, work, and community. Physical climate and psychosocial milieu must also be considered; therefore, social workers and psychologists become important members of the team. (Note: Some assessment teams prefer to complete step 4 before step 3; Some prefer to do these steps concurrently.)

Step 5. Evaluate the user with various devices. Begin by trying off-the-shelf devices, and progress to modifying them, special ordering, and as a last resort, customizing the needed device. In this step it is critical that the therapists, rehabilitation engineer, and vendor collaborate with the user and the careprovider. Many manufactors will "loan" the team equipment for the user to try in various environments. An important factor to remember, is that no one device should be tried in isolation, rather an integrated system must be planned. For example, powered wheelchairs must be compatible with ECUs and augmentative communication devices.

Step 6. Selection of a total AT system in a consumer-provider relationship by all members of the team.

Step 7. Training the consumer in the use and maintenance of all devices is usually the responsibility of the therapists and the rehabilitation engineer with literature and resources being provided by manufactors.

Step 8. Documenting the assessment for the user, careprovider, the inter- and intradepartmental files and for follow-up care is often neglected, but is a necessary step for future referencing and research. Photographs, diagrams, written instructions are also important.

Step 9. Periodical re-evaluation of all parts of the system as the consumer's abilities may change, the tasks may vary, the environments may change, and the AT device may need to be upgraded.

Implications

This approach may seem costly both in time for users and rehabilitation professionals, but the results of users increasing their functional abilities, becoming more independent, continuing to use the AT, and enhancing their quality of life justify the time and effort. This approach is ideal, requiring the involvement of numerous team members, but a resource list of consultants and long-time users can reduce the expense. It should also be noted that in different environments different team members are needed; for example, a teacher is required on a school team and an ergonomist is important in the work place.

Furthermore, AT devices are too expensive to be underused or abandoned. If AT is to become a vital link in the total rehabilitation/habilitation process, then a systematic assessment of all parts of the system is vital.

Discussion

There are several evaluation forms for specific AT devices: powered wheelchairs, ECU's, augmentative communication aids, switches and computer access methods. Most include an evaluation of the consumer's physical abilities, but few consider psychosocial factors such as the consumer's motivation or cognitive ability, such as following directions. Some AT assessments (Scherer, 1991; and Smith, 1991) do consider the environments and tasks. This author proposes that the consumer, all the tasks, all the environments, and devices should be systematically included in an appropriate AT assessment and that this is best accomplished by an interdisciplinary team collaborating with the intended user.

The assessment form developed by the authors and used by occupational therapists, physical therapists, and rehabilitation counselors has five major sections: (1) user's background and goals plus problem that needs to be solved by team members, (2) evaluation of all present and future environments and available support, (3) evaluation of the user's physical, psychological, social, perceptual, and cognitive abilities, (4) status of present equipment and/or devices, (5) proposed AT plan including: first, which tasks the user wishes to accomplish; second, what AT devices the interdisciplinary team members think are important; third, what are the necessary characteristics of the devices required for an integrated system, how and who will train the user, and what funding is available. Space does not permit printing the complete form but copies are available from the author.

References

Bain, B. K. (1993). In Hopkins, H. & Smith, H., Eds., Willard & Spackman's Occupational Therapy, 8th ed., (pp. 325-341) Philadelphia, Lippincott.

Bain, B. K. (1994). Assistive technology in the workplace, in press.

Batavia, A. & Hammer, G. (1990). Toward the development of consumer-based criteria for the evaluation of assistive devices. Journal of Rehabilitation Research and Development, 27, 425-435.

Batavia, Dillard, & Phillip. (1992). How to avoid technology abandonment, Request Rehabilitation Engineering Center, National Rehabilitation Hospital, reprint.

Brooks, N. A. & Hoyer, E. A. (1989). Consumer evaluation of assistive devices. In J. J. Presperin (Ed.). Proceedings of the 12th Annual Conference of the Rehabilitation Engineering Society of North American. (pp. 358-359). Washington, D.C. RESNA Press.

Geiger, C. M. (1990). The utilization of assistive devices by patients discharged from an acute rehabilitation setting. Physical and Occupational Therapy in Geriatrics, 9(1): 3-19.

Phillips, B. (1992). Technology abandonment from the consumer point of view, NARIC Quarterly. Vol 3, #2 & 3, National Rehabilitation Information Center, U.S. Department of Education, Washington, D.C.

Scherer, M. J. & McKee, B. G. (1989). But will the assistive technology device be used? In J.J. Presperin (Ed.). Proceedings of the 12th Annual Conference of the Rehabilitation Engineering Society of North America. (pp. 356-357). Washington, D.C.: RESNA Press.

Scherer, M. J. (1991). Matching Person and Technology (MPT) model and assessment instruments. In Assistive technology device predisposition assessment. Rochester, NY: Author.

Smith, R. (1991). Technological approaches to performance enhancement. In Occupational therapy: Oncoming human performance deficits. (Christiansen, C. & Baum, C., Eds.). Thorofare, NJ: Slack. 747-785.

Beverly K. Bain, Ed.D., OTR, FAOTA
Department of Occupational Therapy
New York University
35 West 4th Street, 11th Floor
New York, NY 10012-1172
Telephone: (212) 998-5823
Fax: (212) 995-4044

ACHIEVEMENT OF PHYSICAL THERAPY GOALS AS A RESULT OF ASSISTIVE TECHNOLOGY USE

Sherry L. Herman-Hilker, P.T.[1], Donn F. Hilker, M.S.[2], and Simon P. Levine, Ph.D.[2]
Physical Therapy Division[1], Rehabilitation Engineering Program[2]
Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center

ABSTRACT

Overlap and interactions between assistive technology and physical therapy outcomes are analyzed. First the roles of a physical therapist and assistive technology specialist at our center are described. Next, potential areas of overlap for people with disabilities from two specific categories are examined. Finally a case report that exemplifies some of the issues addressed is presented.

BACKGROUND

Assistive technology use can result in functional, physical, and psychosocial benefits. The intention of this paper is to look at the use of assistive technology in terms of the potential physical benefits and their relationship to physical therapy goals. Areas of overlap between assistive technology use and the achievement of physical therapy goals will be considered in an effort to determine how approaches to rehabilitation could be modified for improved outcome and/or greater efficiency.

The pediatric rehabilitation program from which the concepts in this paper stem is part of a university-based regional medical center which serves both children and adults, inpatients and outpatients. While a rehabilitation program in which assistive technology specialists (ATS) play an integral part is not unique, it is by no means universal. Hilker et al (1993) described the model of assistive technology and rehabilitation engineering service delivery as it is implemented at our center. These services are a well integrated component of the pediatric rehabilitation program which includes services provided by physiatrists, nurses, physical therapists (PT's), occupational therapists, speech and language pathologists, rehabilitation engineers, rehabilitation psychologists, recreation therapists, social workers, and teachers. The primary goal of this rehabilitation team is to improve the functional independence of the clients who participate in the rehabilitation program. This is achieved through a multidisciplinary approach which facilitates the provision of comprehensive services and recommendations by incorporating the expertise of all those involved in developing the therapeutic plan.

This paper will first describe the roles of the PT and ATS based upon experience at our center. Overlap between assistive technology outcomes and PT goals will be analyzed for the general case of clients with high level quadriplegia and spastic cerebral palsy as well as for a specific case example.

ROLE OF THE PT AND THE ATS

The role of the physical therapist is to address issues related to muscle weakness, paralysis, impaired range of motion, altered muscle tone, decreased endurance, and impaired postural control in order to improve an individual's physical abilities. The methods for improving function and reducing deficits in these areas are many and are limited only by the creativity of the PT providing treatment and the motivation of the patient.

The role of the ATS is to address issues related to technology and its impact on enhancing an individual's functional independence. This is done by introducing the individual to the assistive technology services available, educating the client regarding assistive technology, and by providing opportunities to develop expertise in the use of various types of assistive technology. Successful use of assistive technology requires the identification of specific functional goals. The ATS, together with the rest of the team, must then identify the most appropriate and effective method to address these goals considering the person's limited or residual physical abilities.

OVERLAP

While the PT and ATS are both working towards the improvement of an individual's functional abilities, it is not typical for the PT to use assistive technology to improve physical deficits; nor does the ATS typically address the improvement of strength or range of motion during assistive technology training. However, overlap does exist between the approaches used by the two disciplines. This paper will primarily focus on how a patient's participation in assistive technology activities might lead to the achievement of physical therapy goals. The rationale for this concept is that since the ATS attempts to identify and make use of a person's most reliable and effective motor abilities when recommending appropriate equipment, the assistive technology user could potentially be improving some of the basic motor functions associated with physical therapy goals.

The specific interventions provided by the PT and the ATS will vary greatly depending upon the diagnosis of the client. We have chosen to examine the roles of the PT and the ATS in terms of service delivery to pediatric clients with high level quadriplegia and spastic quadriplegic cerebral palsy. These categories were chosen because they represent situations in which significant overlap of physical therapy and assistive technology outcomes may exist.

High Level Quadriplegia (C_1 to C_3)

A child who has a complete traumatic spinal cord injury at or above the C_3 neurological level will at most have functional use of the face and neck muscles assuming the cranial nerves are intact. He/she would be expected to be independent with talking, chewing, sipping, and blowing, although dependence upon a ventilator complicates the ease with which these activities are performed. The child will be totally dependent in activities of daily living and will need to rely upon attendant care and the use of assistive technologies such as powered mobility, computer workstations, and environmental control systems.

The physical therapy interventions for a child with high level quadriplegia include the following:

- assistance with maintenance of pulmonary hygiene
- passive range of motion

AT USE & PT GOALS

- active range of motion and strengthening of available muscle groups
- pressure relief
- positioning (in bed & in wheelchair)
- powered wheelchair mobility
- patient & caregiver education

In general these physical therapy interventions will be associated with specific goals. For someone with C_1 to C_3 quadriplegia these goals would typically include passive range of motion within normal limits, functional neck strength, tolerance to upright positioning in a wheelchair for functional periods, age appropriate independence in directing care, and age appropriate independence with powered mobility. The ultimate goal of the physical therapy program is to enhance the child's function within his environment and to provide ongoing intervention as necessary to address the child's changing needs.

The assistive technology services for a child with C_1 to C_3 level quadriplegia include the following:

- identification of effective access methods
- provision of environmental control training & opportunities
- computer access/literacy training
- powered wheelchair mobility
- wheelchair seating & positioning
- recreational opportunities using assistive technology
- patient & family education

Assistive technology is critical to functional independence for children with high quadriplegia. The goal of the ATS is to identify the equipment and services necessary to give these children the ability to access computers, environmental control systems, mobility systems, and modified toys or games so they are able to participate in functional activities, recreation, and exploration. Reliance on assistive technology will be lifelong and will contribute to the child's social, educational, and ultimately vocational development.

Assistive technology use may contribute to the achievement of the physical therapy goals described above. A child who is practicing with computer access, environmental control, or adapted toys using a mouth stick or head-pointing mouse emulation system can be positioned to provide the opportunity for developing improved cervical muscle strength and head control. This may also be true of the child using sip-and-puff, a voice recognition system, or a chin joystick. Sitting tolerance and endurance can also potentially be improved if the child performs the assistive technology activities from a sitting position in his wheelchair.

Cerebral Palsy/Spastic Quadriplegia

Functional capabilities of children with cerebral palsy (CP) are extremely variable therefore discussion will be limited to adolescent clients with spastic quadriplegia. The physical therapy interventions for a child with spastic quadriplegic CP vary depending upon the individual's level of function, but in general they include the following:

- passive range of motion & stretching
- facilitation of isolated motor control & strength
- wheelchair seating & positioning
- facilitation of independent mobility
- patient & caregiver education

In general the physical therapy goals for an adolescent with spastic quadriplegic CP are related to improving an individual's independence. Because of the variability in function of these clients it is difficult to describe specific goals. General goals include prevention of contractures and deformity, functional use of isolated motor control, improved postural control and positioning, and independent mobility.

The assistive technology interventions for a child with CP are also variable depending upon the individual needs. Typically they may include the following:

- identification of effective access methods
- augmentative communication
- computer access/literacy training
- powered wheelchair mobility
- wheelchair seating and positioning
- provision of environmental control training & opportunities
- recreational opportunities using assistive technology
- patient & family education

Frequently these children have had exposure to assistive technology through experiences in the community prior to coming into our program. In this case, the goal of the ATS is to supplement their knowledge and experience regarding assistive technology and to work with existing professionals and service providers in the community to improve functional use in communication, education, recreation, and ultimately vocation.

A child with CP who is being trained to access and use an augmentative communication device or computer, can be positioned so that accessing the system is successful but challenges his/her isolated motor and/or postural control. Strategically placed input devices can result in therapeutic gains particularly if the child's performance is motivated by a desirable outcome. For example, a child who is working on bringing his hands to midline may be motivated to hit a selection on an expanded keyboard (key at midline) during an enjoyable computer activity. A carefully arranged workstation can challenge postural control, particularly if external supports (such as a wheelchair headrest) are removed for purposes of the session so that the child must rely on his/her own abilities to participate in the functional activity. Use of headpointers, expanded keyboards, trackballs and hand switches can be structured to promote development of neck strengthening, head control, postural control, upper extremity coordination, endurance and sitting tolerance. Design of specific activities and objectives will be specific to the individual client.

CASE EXAMPLE

It is helpful to look at a particular patient case that exemplifies issues discussed above. JT is a 13 year old boy who became paralyzed at the level of C_1-C_2 when he was nine years old. He is ventilator dependent and has no motor or sensory function below the level of C_2. Within 72 hours of his admission to our pediatric intensive care unit both physical therapy and assistive technology evaluations had been completed and goals established. Physical therapy goals included: increased neck strength and head control, maintenance of passive range of motion, improved wheelchair sitting tolerance and endurance and independence with powered mobility. Assistive technology goals included: successful control of the environment through the use of an environmental control system, independence with computer access following set up, and independence with powered mobility.

Initially both the physical therapy and assistive technology activities were performed at the bedside. After approximately two months of hospitalization, however, JT was able to tolerate sitting in his wheelchair throughout the day for participation in physical therapy, occupational therapy, speech therapy, neuropsychology and assistive technology activities. During physical therapy, JT would participate in diversional activities such as playing games to distract him as he worked on improving his sitting tolerance. As JT became more involved in his assistive technology program it was not uncommon for him to spend additional hours after his day of therapy engaged in assistive technology activities (such as computer access and Hands Free Nintendo™) which resulted in additional time spent in his wheelchair. Although the assistive technology goals did not specifically include sitting tolerance and endurance it is likely that JT's frequent use of the technology for extended periods of time contributed to improved sitting tolerance and endurance in his wheelchair.

During his 10 month hospitalization JT participated in approximately 35 hours of strengthening and head control activities in physical therapy. The goal of these activities was to facilitate the achievement of functional neck strength for head control in his wheelchair, during transfers, and for accessing his assistive technology. JT was concurrently involved in assistive technology activities related to computer access which may have facilitated neck strengthening. During the 10 month stay this amounted to 45 hours specifically using a head-pointing mouse emulation system. This does not including hours spent using sip-and-puff, Hands-Free Nintendo™, or other assistive technology activities for which active neck movement is not required (but may be used none-the-less).

Initially JT was unable to use a head-pointing mouse emulation device due to lack of head control. As the PT documented increasing neck strength the ATS was documenting increasing ability to use the head-pointing device. Whether use of this device contributed to neck strengthening cannot be stated for sure, but it would not be surprising to find that participation in these functional activities did have a positive impact on JT's neck strength and ultimately on head control.

JT was exceptionally motivated to use technology available to him during his hospitalization. He continues to use it functionally now, is keeping up with his eighth grade class, and is learning vocational computer skills.

DISCUSSION

The populations discussed in this paper were chosen because of the overlap between physical therapy goals and the physical benefits of assistive technology use. Although the overlap is less obvious in other patient populations it does exist. For example, in the case of a paraplegic client physical therapy goals might include sitting balance, normal upper extremity strength, and independence with bed and wheelchair mobility. The assistive technology goals would most likely be related to computer literacy. In this situation functional activities in pursuit of physical therapy goals could readily be incorporated into the assistive technology program. The individual could transfer out of the wheelchair onto a surface on which he/she is unsupported. This would allow practice with sitting balance and endurance during computer training. With a little ingenuity similar activities could be designed and implemented for clients with a wide variety of diagnoses, whether inpatients or outpatients, and whether children or adults.

Care must be exercised when creating this type of program to avoid compromising assistive technology performance by making the incorporated physical activity too challenging. If the challenge is too difficult assistive technology outcomes may be sacrificed. However, short term results should not be the only consideration; long term benefits should also be a factor in the design of activities. Initial physical challenges may limit the quality of the functional outcomes during AT use, but potentially over time may result in improved physical ability which in turn may allow more effective assistive technology use.

Health care professionals have a responsibility to scrutinize their service delivery and attempt to identify the most efficient ways to provide high quality care. Designing an assistive technology program so that physical outcomes can be achieved as a result of its use is one way that efficiency could be improved. Although this paper is written from the point of view of how physical therapy activities could be incorporated into the assitive technology program it is recognized that it is also true that assistive technology activities could be integrated into the physical therapy program. Both ways could potentially improve efficiency by allowing the patient to address goals from each discipline concurrently during either the physical therapy or assistive technology session. Rehabilitation patients and their service providers generally have very demanding schedules and reduction of time spent addressing some goals may allow more opportunities to address other goals or participate in other activities. It is also possible that the goals may be achieved more quickly thus leading to a shorter inpatient stay or treatment duration.

Although this discussion has been primarily about the coordination of services between PT's and ATS' it is recognized that this type of program could be developed between other rehabilitation professionals. Consideration of the types of overlap discussed in this paper may lead to innovative concepts of service delivery. Hopefully, the traditional division of services between disciplines can be modified to take advantage of efficiencies such as those described in this paper. The overlap which exists in rehabilitation interventions provides a natural opportunity for investigating methods which allow different disciplines to work together to improve the effectiveness and efficiency of treatment. Further research is required to demonstrate how such a coordinated program could affect rehabilitation outcomes.

REFERENCE

1. Hilker DF, Levine SP, & Waring W. (1993). A Model of Rehabilitation Engineering Services in an Acute Rehabilitation Setting. *Proceedings of the 16th Annual RESNA Conference*, RESNA, 20-22.

ADDRESS

Sherry L. Herman- Hilker, P.T.
F2593 C.S. Mott Children's Hospital
University of Michigan Medical Center
Ann Arbor, Michigan 48109-0224, USA

STATE OF THE HEART - ASSISTIVE TECHNOLOGY IN EUROPE

Gunnar Fagerberg and Tomas Lagerwall
The Swedish Handicap Institute
Vällingby, Sweden

ABSTRACT

HEART has been a large study of assistive technology in Western Europe. Several different aspects have been studied. Data have been collected and analyzed. Conclusions, recommendations and proposals for action cover a broad area.

BACKGROUND

The creation of a single market in Europe opens up new opportunities to meet the needs of the users. However, the assistive technology market is complex. Although based on technological innovation, development and manufacture, there are many different actors and factors that impact the market in very important ways. Many of these are regulated by national legislation, procedures, organisational structures, tradition and culture and by international endeavours such as standardization and cooperative research and development.

HEART (Horizontal European Activities in Rehabilitation Technology) was launched by the TIDE (Technology Initiative for Disabled and Elderly People) program in the European Commission to address some issues related to the European assistive technology market.

OBJECTIVE

The ultimate goal of the study was to improve the life situation for persons with disabilities and elderly persons enabling them to live independently by creating a European single market in assistive technology.

APPROACH

The study covered six areas, or lines: Standards, testing and certification; Coherence in industrial sectors; Service delivery; Legal and economic factors; Training; Emerging areas of research and development.

Each line had a designated Line Leader and line members. The Line Leaders together with the Main Contractor formed the Management Committee. Altogether, the HEART consortium had 21 member institutions from 12 countries.

Each line collected and analyzed data, much of which has never been compiled before. Conclusions and recommendations for action were presented.

Since the HEART study to a large extent was pioneering work, not previously carried out with such scope and depth, new methodological developments had to be made and applied.

The study on service delivery systems resulted in useful tools for the description and analysis of service delivery systems. Service delivery processes were described in seven steps that appeared to be applicable to almost all systems: initiative, assessment, typology of the solution, selection, authorization for financing, delivery and management/follow up.

The six quality criteria developed - accessibility, competence, coordination, efficiency, flexibility and user influence - were also of substantial practical and theoretical value. The great number of statements about good service delivery resulting from the study were the first operationalization of these criteria.

A new model for user participation in standardization work was developed. The model was tested in an actual case and found useful for future standardization efforts.

The area of socio-economic evaluations was the subject of a study of methodology. Strengths and weaknesses in existing methods were described, case studies were reported and suggestions for further refinement of methods were given.

A structured analysis of equipment and services for interpersonal distance communication for people with disabilities was made. Existing equipment and services were analyzed, identifying problems in performing the necessary tasks and available solutions for different user groups.

The possible impact of technological developments in telecommunications, with the

81

main emphasis on the work environment, was identified. Both new barriers and new opportunities for people with disabilities were analyzed.

Potential synergies between assistive technologies and emerging technologies have been identified and their potential impact assessed.

RESULTS

The results of the HEART study confirm the fragmentation of European assistive technology market because of geographical, cultural and political differences.

The market for assistive technology products is closely linked to the service delivery systems in the different countries. The cost is often covered in whole or in part by a third party payer, be it the national, regional or local government, an insurance company or a charity organisation.

The study showed that the service delivery systems in European countries vary considerably in basic principles, actual procedures and coverage. In one single country, there may be several systems. Information about the systems, their rules and numerical data is difficult to find and interpret, for users and distributors. The information on service delivery systems in 16 countries collected by HEART (3) is in itself an important contribution to the field.

Many systems require type testing of products before reimbursement approval. Testing laboratories have generally little contact and the methods used are inconsistent.

The majority of assistive technology companies are small or very small. In France, very few firms have more than 50 employees, but most companies employ only two or three persons. In Norway, the range of employees is between 1 and 150, where many have less than ten. Most of the manufacturers are active in only a few sectors of assistive technology.

Consequently, most companies do not have the capital or human resources to engage in collaborative research and development. Research is not coordinated and research results are not disseminated efficiently. Many companies tend to stay within their national market or a few neighbouring countries. A frequent observation is that there is little contact between industry and the actual users of the products.

There are considerable differences in legislation for older and disabled people in the countries studied, as well as the actual implementation of the legislation.

Another indication of the heterogeneity of the assistive technology field is the lack of common definitions. A contribution of this study is methodological developments concerning concepts within standardization, service delivery, socio-economic evaluation, education and research.

While these and other results confirm the fragmentation, other circumstances and initiatives work toward convergence, collaboration and coordination of efforts.

Standardization is frequently mentioned as an important tool to strengthen the single market. In the HEART study, new product categories in need of standardization have been identified as well as ways to make the standardization process more efficient and more responsive to user needs and requirements.

European cooperative research and development action is an important mechanism to further convergence and the single market in Europe. Especially the TIDE program has brought together different types of actors from different countries in close cooperation within project consortia. The HEART consortium is a good example of the networking created by these projects.

Another development in the same direction is the creation of a European society in the field of assistive technology. HEART has made a feasibility study and started preparing the launch of the society, which will take place at the TIDE Congress in April, 1995 and the ECART 3 conference in October, 1995.

CONCLUSIONS

The six lines of the HEART study have reported their methods, findings, conclusions and recommendations in several reports (4). Some examples of conclusions are:

- Standards are important to ensure safety, compatibility, durability, quality, performance and accessibility. The most important requirement of people with disabilities is accessibility.
- The main bottlenecks reported by industries concern lack of information about user needs and standardization, lack of communication

between users, professionals and the industrial partners, and lack of knowledge of users and professionals about technical aids on the market.

- A good assistive technology service delivery system should be accessible, flexible, coordinated, efficient, with adequate competence and user influence.
- In future revisions of the European Union Treaties, new competences should be considered, empowering the Union to combat discrimination on the grounds of age and disability.
- All training programmes must include human, technological and socio-economic components and have both an environmental and a user perspective.
- Various mechanisms for technology transfer should be operated at regional, national or European level. A proposed new organization should take responsibility for the implementation and operation of the mechanisms.

The findings and conclusions from the HEART study have led to over one hundred recommendations for action. The HEART Management Committee recommends that:

- The European Commission launch an information programme on assistive technology with the purpose of raising awareness, increasing the knowledge level of actors inside and outside the field and providing continuous information about new developments.
- The European Commission carry out a study to determine how coordination of assistive technology activities and networking at the European level can be achieved. Structure, organisation, scope, mandate and functions should be studied and action to establish such coordination be taken.
- As a long-term measure, the European Commission take action to promote legislation leading to equal opportunities and full accessibility for people with disabilities and older people.
- As a short-term measure, the European Commission and national governments guarantee that the needs of people with disabilities and older people are taken into account in all relevant legislation, programmes and initiatives.
- The European Commission and other funding sources, national and international, support the follow-up and update of HEART work and other studies in assistive technology.
- The European Commission and national governments involve user representatives in all instances where issues on disability are treated and ensure that aspects of special concern to older and disabled people are taken into account in all programmes.
- Industrial and commercial actors in the field of assistive technology explore and initiate national and international interest associations creating a critical mass, which could be the starting point for various activities.

REFERENCES

1. Fagerberg, G. and Lagerwall, T. (1994) HEART - A Study on Assistive Technology in Europe. Proceedings of the RESNA '94 Annual Conference. RESNAPRESS, Arlington, VA.

2. Fagerberg, G. and Lagerwall, T. (1994) Main Contractor Final Progress Report. HEART Study (TIDE 309). The Swedish Handicap Institute, Vällingby, Sweden.

3. European Service Delivery Systems in Rehabilitation Technology - HEART Line C (1994). Edited by L. de Witte, H. Knops, L. Pyfers, P. Röben, I. Johnson, R. Andrich, M. Parker and S. Forsberg. IRV, Hoensbroek, The Netherlands.

4. The HEART Study (TIDE 309). 23 public reports from Lines A-F. The Swedish Handicap Institute, Vällingby, Sweden.

ACKNOWLEDGEMENTS

The HEART study was initiated and funded by the European Commission, Directorate-General XIII, Technology Initiative for Disabled and Elderly People (TIDE). Project liaisons and a never-failing source of assistance and encouragement were Egidio Ballabio and Ramon Puig de la Bellacasa.

Gunnar Fagerberg
The Swedish Handicap Institute
Box 510
S-162 15 Vällingby, Sweden

ACCESSIBILE HOUSING IN EUROPE. POLICIES AND RESULTS

Ivor Ambrose,
Danish Building Research Institute

ABSTRACT

Accessibility and *Adaptable Housing* are key concepts in the promotion of supportive environments for the physically challenged. This paper presents a broad overview of building-related legislation in European countries on the subjects of Housing Adaptation, Adaptable Housing and Use of Computers and Information Technology. The study was initiated and carried out by a European group of users, researchers and service-providers under the umbrella of the HELIOS program of the European Union. Policies are shown to vary widely across Europe and there is a great need for description and exchange of good practices.

BACKGROUND

As part of the HELIOS II Action Program for Disabled People, a European working group of users, researchers and service-providers was formed to exchange experiences on the subject of accessibility in housing. The group prepared its own work programme having identified a need for better knowledge of the goals and means for achieving accessibility for all in residential environments.

Several questions and problems underlie the current state-of-the-art in accessibile housing. Many European countries are moving from *mandatory design specifications* concerning housing design to building regulations which specify *functional requirements* which the architect, builder and client must uphold. This policy movement - towards framework legislation - places responsibilities on all parties who are involved in building design to find appropriate solutions to questions of accessibility, space usage, design of fixtures and fittings, integration of services for new information technologies, etc. Meanwhile governments and agencies in different countries also prepare and promote design guidelines which, when compared, show considerable variations in intent and in the solutions they present.

The particular concept of *Adaptable housing*, whereby housing is designed to accept later adaptations if needed, has gained acceptance in some countries but is poorly understood in others.

The challenges of different forms of disability - especially sensorial and cognitive - have also been largely ignored both in building legislation and in guidelines.

Furthermore there are often discrepancies between building legislation, recommendatory texts and the systems og subsidies, grants and loans which are available to persons who wish to adapt their home to their particular functional requirements.

OBJECTIVE

A survey was carried out in October - December 1994 to identify policies and practices in Europe, covering the following themes:

- Legislation concerning housing for the disabled/accessible housing
- Legislation concerning housing adaptations, financial support
- Policies concerning adaptable housing
-Innovative examples of housing types and housing policies which further accessibility and independent living
- Examples and evaluations of the uses of Information Technologies in housing in order to further independent living
- Education of architects in "Design for All".

METHOD

A survey questionnaire was drawn up jointly by the participants in the working group and therefore reflected the interests of user groups, and those who were close to the design process, either as legislators, public servants, or housing and service providers.

This survey was designed to gather information on differing national approaches to the problems of and solutions to housing accessibility and new technologies.

RESULTS

National housing legislation in Europe continues to exhibit different priorities and these may be reflected in differences in norms and standards. Recommended dimensional criteria for accessible housing differ from country to country, although some (eg. the Nordic countries) have made deliberate efforts to coordinate their standards. But in general both similarities and differences in standards are almost always the product of chance rather than intention: different historical backgrounds or cultural emphases also play a role.

Looking beyond building legislation to other policy areas it is notable that there can be administrative confusion and "gaps" which can trap both disabled persons, well-meaning architects and housing providers. If there is to be greater harmonization between building legislation and other practices, such as support for home adaptations, then the use of different policy instruments requires - first and foremost - an improved flow of knowledge between the relevant sectors of government. Such information exchange could then lead to common goal-setting and more consistent legislation and use of incentives across the sectors involved.

A major concern of this study was to document the means for adapting houses to fit user requirements and, in particular, so-called adaptable housing. Adaptations can be made to housing in many technical ways. The range from low-tech to high-tech might go from simple ramps for wheelchair access to environmental control devices (eg. door-openers, ventilation, remote cameras) operated by infra-red remote controllers or radio waves. All adaptations - whether small or large - cost money, and seen from a total building economy point-of-view such expenditure adds to the price of housing. In some countries and in some cases these extra costs are not borne by the person who builds the house but by the resident and the state or municipality together, or the state alone. If the house in question is not particularly accessible in the first place rhen the price of adaptations might be extremely high. So high that the resident may be obliged to move to another house.

In the late 1980's Dutch housing corporations developed the idea of adaptable housing as housing designed with forethought - deliberately programmed and built to accommodate eventual changes to suit a disabled resident. The strategic value of this initiative was recognized not only in The Netherlands but also in other European countries. The European Commission also supported the Dutch work, sponsoring a seminar on the subject (*Building Adaptable Housing* 1988).

Today examples of housing *built to adaptable standards* may be found in Norway, Sweden, France, Italy, Spain, Greece, The Netherlands and Denmark. Yet, strictly speaking, it is only *official government policy* to build such housing in the first five countries on the above list. In the remaining countries the policy of building adaptable housing is encouraged and effectuated through various incentives, private initiatives and cooperation between public and private actors. Non-legislative means are used in many ways to further accessible housing, eg. local agreements between architects' unions, municipalities and house builders.

A specific question on whether architecture students receive obligatory courses in design for people with disabilities gave only *one* positive answer, from Sweden. Several respondents could point to the exitence of optional classes and courses but the general picture gives little hope that architects in general have attained a (general) understanding of the design requirements of the disabled. The situation for professional continuing education of architects on the same subject, where mentioned, also looks bleak.

In many ways the application of information technologies can be regarded as a special from of housing adaptation. Many advanced technologies which are available today are closer to the user than to the dwelling or building, for example sensory aids. But new devices are finding their way into homes in order to provide security, support for daily activities, environmental control and even medical care. On the basis of the questionnaire survey, developments in this area are incremental and at a low level. There is a small scattering of demonstration "smart houses" in Europe which incorporate sophisticated technologies and more are on the way. But the general picture is one of unfulfilled promise, at the present point in time. Respondents also indicate that competing standards in the industry plague development. Evaluation studies relating to the new technologies are also lacking. Perhaps the most interesting study has taken place in Norway, where the concepts of life-span accessible housing and information technology applications have been integrated in the highly regarded BESTA project.

DISCUSSION

This paper presents a structured overview of European policies regarding accessibility in housing environments. The study has highlighted and exemplified many areas where knowledge needs to improved and where policies must be better coordinated. Examples of good practice are also given, showing how further policy development must make use of research and development in the rehabilitation field.

REFERENCES

Bjørneby, S. and Taipale, V. 1994. *Access to Technology* In: COST A5, *Ageing and Technology, proceedings of the workshop on Elderly, elderly disabled and technology* Commission of the European Communities, DG V and DG XIII. Ed. Jan Ekberg.

CABA 1990 *Applications of Building Automation for Elderly and Disabled Persons, vol. I & II.* Vol I Analysis of demand (consumer needs) and supply (automated building technologies) in order to match technology and need, Vol. II survey report on needs of elderly and disabled people. Canadian Automated Building Association, Ottawa.

Disability Action. 1993 *Adaptable Housing. Why? How? When?* Disability Action, Belfast

Nolte, E.A.H. 1988 *Building Adaptable Housing.* National Housing Council. Commissioned by the Department of Action for Disabled People of the European Communities. NWR, Almere.

Ambrose, I. and Nolte, E. (eds). (In press) *European Approaches to Accessibility and Housing Adaptation.* HELIOS, Brussels.

ACKNOWLEDGEMENTS

The author acknowledges the assistance of the HELIOS WT8 Working Group on Adaptable Housing in carrying out the survey which is the subject of this paper. Thanks also go to Mary Kyriazopoulou, Team of Experts at the HELIOS office, Brussels.

Ivor Ambrose
Danish Building Research Inst.
Housing and Planning Div.
Post Box 119,
DK 2970 Hoersholm
DENMARK

Tel: (45) 42 86 55 33

Fax: (45) 42 86 55 94

E-Mail ia@sbi.dk

QUALITY MANAGEMENT SYSTEMS IN WHEELCHAIR PRESCRIPTION

Paul Richardson, David Calder
Rehabilitation Engineering Division, Medical Engineering & Physics, King's Healthcare, London, England

ABSTRACT.

On April 1st 1991, in England, the provision of Wheelchairs, Seating and Accessories was handed over to the National Health Service (NHS) from the Civil Service. Although this resulted in a refreshing and necessary change in the way that wheelchairs and their accessories were prescribed it did not address the actual process of prescription of these articles in terms of the system.

With over 400,000 wheelchair users this lack of a precise quality management system can and does lead to substantial waste of resource.

In October 1991, the Rehabilitation Engineering Division of Medical Engineering and Physics, King's Healthcare, conducted a pilot survey of the way prescription occurred. This small study identified a large number of areas where the system could break down Experience elsewhere confirmed that the system did indeed break down.

In November 1992 the implementation of a quality management system started. The objectives, procedure and progress are outlined in this paper.

BACKGROUND.

The devolution of the prescriptive process for wheelchairs, special seating and accessories from the Civil Service of the Government, to the National Health Service, in 1991, carried with it refreshing and necessary changes in the way that these equipments were provided to over 400,000 users in England. On the downside, no actual systems were transferred over into the new structure and inevitably this resulted in increased workload as those involved attempted to rectify logistical and prescriptive errors.

In October 1991, the Rehabilitation Engineering Division (RED), of Medical Engineering and Physics, King's Healthcare, conducted a pilot survey of the way prescription occurred. RED provides technical support to approximately 28 Health Districts around London, UK, each district catering for approximately 3000 wheelchair users. The survey was carried out by a member of staff, an engineer and accredited Quality Auditor.

This small study identified a large number of areas where the system could break down, where for instance there were open loops or where there were no checks against the initial referral of the patient to ensure that the correct prescription was being effected. The experience of Rehabilitation Engineers in other districts confirmed that the system did indeed break down.

The number of wheelchair users logged into the NHS has risen since the devolution, in some cases dramatically (>38%). During the course of the audit it became increasingly clear that the pressure on the clinical services was creating a situation in which things could very easily go wrong. By employing quality systems, which in many cases are nothing more than sophisticated checklists, it was ultimately possible to relieve some of the pressure on the clinical personnel involved. This had a beneficial effect for all concerned, particularly the wheelchair user.

OBJECTIVES.

The specific project objectives were set as follows:

1. To completely audit the prescription system for Wheelchairs, Cushions, Special Seating and Accessories.
2. To identify the weak links and open loops in the present systems.
3. To construct and trial a model prescription system.
4. To devolve this system to other districts in the area served by RED.

APPROACH.

To audit the wheelchair prescription process we made the decision at the start of the project to employ a Quality Engineer to act as the lead Auditor. The engineer was managed by the Project Leader and fed back to the internal Quality Group of RED.

The philosophy behind choosing a quality engineer rather than an external consultant was that

87

we anticipated a need to have somebody working within the organisation who would be perceived by the staff to be 'on their side' and working day to day with them to create a Quality System.

The project was split into eight phases, each phase being controlled and verified by our quality group in order to ensure project continuity. The eight phases used were as follows:

1 Write an audit specification using ISO9000 (1) criteria for every stage of the prescription process.

2 Conduct the audit in two DHAs, Camberwell and Brighton (geographical situation and patient population of these districts being distinctly different).

3 From the results of these audits construct model prescription systems that would satisfy:

   a) The districts concerned
   b) The criteria of ISO9000

4 Upon agreement of the model system prepare a skeleton Quality System Manual for Provision of Wheelchairs and Accessories.

5 Review the proposed QSM with the districts and the RES Quality Group. Modify where necessary.

6 Prepare prototype documentation for the system. Inevitably this would include both paper and electronic media.

7 Trial the system in the districts.

8 Review the system, incorporate feedback and handover to the districts, with a full report to the Region. Districts pick up the further running and use Clinical Audit to establish benefits.

RESULTS.

In our original application we had projected possible findings and outcomes, and were pleasantly surprised that in all 6 projections there was significant agreement from the initial audit. These were as follows:-

1. Referrals
General lack of information on the referral documentation causing inappropriate further prescription.

2. Assessment
Assessments conducted without correct personnel ('The Team') because of poor referral process.

3.The Prescription
A lack of formal auditing or vetting of the prescribed solution(s). Again, difficult to conduct effectively if the referral (1) is poor.

4.The Local Wheelchair Service
No effective progressing systems and very little in the way of cost checking systems. Habitual use of suppliers rather than identification of 'best for the job'.

5. The Suppliers
Although some suppliers are monitored as a result of contracts, many are not monitored in any way. There is no acceptance testing to established standards. Quality standards are missing totally in some cases or being ignored by the suppliers.

6.The Client
The client is at the beginning and end of the process and needs a system with built in checks. The aim of this study is a 'one visit' outcome as far as the client is concerned.

DISCUSSION.

As a consequence of the project the Operations Manager of the Disablement Services Centre at Dulwich decided to register under ISO9000.

The major area of input on the Project has been and still is, the design of the clinical documentation for the referral, assessment and prescription parts of the process. It has been an extremely interesting area to have worked in partly because of the truly multi-disciplinary aspects involved. We have designed and trialled and following a review, modified and implemented new documentation that has been generated as a consequence of system reviews by Therapists and Engineers. This iterative process continues with new ideas being input by every member of the Team from Consultant through to voluntary helpers and carers. Various new considerations towards the wheelchair user and his needs have been implemented as a consequence of this review method.

The philosophy of the documentation design has evolved towards an 'answer in the box' technique. In practical terms this means that when reviewing completed documentation from a clinical session, if a box does not have an answer in it then the assessment is incomplete. This simple visual check significantly aids efficiency in ensuring that the questions have been answered.

A good example of this is the new Special Seating Assessment Form which not only acts as an assessment report but also as a script which prevents any detail being overlooked. Due to its layout one can easily check the form for completeness and the use of tick boxes allow the quick record of demonstrations or any special tests that have been carried out during the assessment. The information within the document is assessed at clinical review where any future development can be identified. Time savings have already been identified as a consequence of the implementation of this form from both the clinical and administrative departments. Instead of notes or a tape going for typing at the end of a clinical session, the report can be photocopied (within the quality constraints on photocopying documents!) and issued immediately. Problems identified in the past with illegible handwriting have been almost totally eliminated by the form of the documentation.

Comment from the Operations Manager of Dulwich DSC: "We recognised the need to review the way prescriptions for wheelchairs, accessories and their associated seating were processed within the service. This Project has provided the means to carry out this enormous and important piece of work, with the added advantage of providing complete documentation and taking the service through to ISO9000 registration".

In summary the project has identified the following needs for the development of operation systems within the Local Wheelchair Offices:-

1. The use of a formal quality system to develop quality service management systems is both practical and effective in the clinical environment.

2. When undertaking such a project the use of a professional quality engineer is particularly effective. Although this has a cost implication the benefits of having a focal point that is not part of the executive outweighs the capital outlay.

3. The target office / department must form a quality team from its ranks providing a sense of control and ownership.

4. The use of outlying skills of the team which are identified in their profession and experience.eg, the use of Rehabilitation Engineers to undertake / lead audit programmes.

5. That professional bodies adopt quality systems into their recommended training / apprenticeship profiles.

6. The commitment of staff and suppliers to the local service.

REFERENCES.

1. International Standards Organisation, ISO 9000 "Quality Systems".

ACKNOWLEDGEMENTS.

King's Healthcare NHS Trust, London, England.

King's Healthcare Rehabilitation Centre Management & Staff.

Sussex Rehabilitation Centre Management & Staff.

Quality Management & Training, Guildford College of Technology, Guildford, Surrey, England.

D Calder
Rehabilitation Engineering Division
King's Healthcare Rehabilitation Centre
Bowley Close
Farquhar Road
London SE19 1SS
England

Phone: +44 171 346 3705
Fax: +44 171 346 3706

SIG-02
Personal Transportation

Whiplash Injury Risk to People with Disabilities Traveling in Wheelchairs

Glenn R. Paskoff
Transportation Rehabilitation Engineering Center
University of Virginia

Abstract

A large number of studies have been conducted examining the mechanisms resulting in whiplash injury as a result of automotive accidents. Despite the fact that many of these mechanisms are still not clearly understood, very little has been documented concerning the possible risks that rear impacts present to wheelchair users. As it stands now, there is no existing U.S. standard regarding protection of mobility aid users from rear collisions. This paper will discuss the importance of these issues and outline the research which will be performed in the Spring of 1995.

Background

Rear impacts have been given a low priority in automotive crash test research for a long time. This is primarily due to the fact that only 3.5% of fatal accidents are the result of rear end accidents. However, accident statistics indicate that 24% of all injuries are caused by rear impacts (Data Link, 1990). Of these, neck injuries are the most common. In a study by Hohl (1974) of 146 patients with automotive neck injuries, about 74% were the result of rear impacts. Often neck injury symptoms do not develop until hours or even days after the accident. As a result, they are not always reported as serious injuries to police accident investigators and are given a low AIS (Abbreviated Injury Scale) value of 1 or 2. In addition, chronic pain and disability from whiplash have been known to persist for years after the injury, with little or no method of rehabilitation (States, 1979).

One of the problems with diagnosing whiplash is that its definition is rather ambiguous. The term itself is misleading because it implies that the dynamic motion of the head/neck resembles the motion of a cracked whip, which is not always the case (Walz, 1994). It is often loosely defined as an acute strain of the cervical spine acquired without the application of a contact force to the head or neck. Hyperextension, or excessive rearward bending of the head and neck, is the most frequent injury mechanism for whiplash, and rear impact automobile accidents constitute the majority of hyperextension incidents (States, 1979).

Over the years, researchers have conducted studies to determine which factors are the most significant in preventing whiplash injuries from occurring in rear-end accidents. Seat back height, seat back stiffness, and the presence or absence of a head restraint device were identified as important factors and were incorporated into automotive seat design (Viano, 1992; States, 1972; Mertz and Patrick, 1967; Svensson and Lovsund, 1993; Severy et al., 1969). Consequently, the possible risk of a neck injury occurring due to rear impacts has been lessened over the years.

Some physical characteristics have also been found to be related to whiplash injury. Some of these are gender, age, body build, arthritic changes in the cervical spine, seated position and position at the time of impact (States, 1972).

Several phenomena have been observed with rear impact studies. Two of the most prominent of these are ramping and differential rebound. Ramping occurs when the dummy tends to slide up the back of the chair during impact. In some cases the dummy struck his head on the top of the crash buck. It was found that lap belts tend to minimize this problem by keeping the pelvis down on the seat. The only exception to this resulted when seat back failure occurred, allowing the dummy to slide out from under the belt (Viano, 1992).

Differential rebound occurs when the elastic properties of the seat back push the torso in a forward direction while the head and neck are still moving backwards, due to their inertial forces. This type of action greatly aggravates the possibility for whiplash injury (Svensson and Lovsund, 1993). Accident investigations and clinical studies by States (1979) have revealed that hyperextension injury may occur even with properly adjusted head restraints.

Statement of the Problem

Statistical surveys quoted in a recent report by ECRI (1993) stated that approximately 2/3 of an estimated 1.5 million mobility aid users require special transportation services and an average of 1.2% of all transit riders have disabilities. This represents a significant percentage of the vehicle occupant population.

Federal Motor Vehicle Safety Standard (FMVSS) 207 specifies that the upper cross member of the seat back must withstand a static load of 3,300 in-lbs of torque. Assuming that a moderate rear impact results in an 8-10 G deceleration, a 50th percentile dummy would impart a force of approximately 900 lbs. acting at the center of gravity of the torso plus the head (about 12 inches above the buttocks). This results in a moment on the seat back of over 10,000 in-lbs, more than three times the specified load (Red, et al., 1982). While current automotive seats easily surpass this minimum load requirement, typical wheelchair seat backs do not (Red, et al., 1982).

Wheelchairs were not originally designed with crashworthiness in mind. In fact, a study by Red, et al. (1982) tested several models of wheelchairs in frontal, lateral and rear collisions. They found that wheelchairs are structurally deficient in the lateral and rear crash directions. As a result, the occupant was placed at a much higher risk for sustaining an injury.

After an extensive review of the automotive occupant kinematics involved in rear impacts, Severy, et al. (1969) recommended that seat backs be a minimum of 28 inches. However, most wheelchair backs are only 18 inches high and do not have a head restraint. In addition, head rests that are available for some wheelchairs are not designed to survive in a crash environment.

Approach

Several dynamic tests will be conducted to evaluate the protective performance of wheelchairs in rear impacts. To provide a comparative analysis, standard automotive seats will be tested as well as wheelchairs. Computer simulations will be used to lend weight to the experimental results.

Dynamic testing will be performed using a rigid aluminum platform that is accelerated down a 60 foot track by the force of compressed air and a piston stroking through a cylinder. A Hybrid III dummy will be seated in a wheelchair and face backwards on the sled. A crash-repeatable surrogate wheelchair developed at UVA will be tested along with some commercially available wheelchairs. The tie-down used for these tests will be a four strap system which was also developed at UVA. Standard production automotive seats will also be tested.

It will be assumed that most wheelchair users will be traveling in privately owned modified vans, in buses, or in public paratransit vehicles specially designed to carry wheelchairs. Since modified vans are the smallest of these vehicles, they represent the most severe risk to the occupant. Therefore, the crash pulse that we will use will be based upon an actual pulse from a van involved in a rear impact.

High speed cameras will record the crash tests at 1000 frames/second. Data sampling will be digitized using DSP Technology TRAQ P data acquisition program at 10,000 samples per second. Anti-aliasing will be in accordance with SAE Recommended Practice J211. In order to examine the head/neck angles, film analysis will be performed, using a NAC film analyzer and MAP software. An assessment of the likelihood of injury will be made by evaluating parameters relevant to rear impact injury modes. According to Mertz and Patrick (1967), head torque is the major factor in producing neck injury. However, head/neck angles, head torque, and neck axial loads will be measured and compared with accepted values for human impact tolerance, as they are documented in previous literature.

The computer simulations will be performed using a DYNAMAN simulation package to model the interaction between the wheelchair and the dummy. This model has accurately predicted occupant kinematics and forces in previous testing (Pilkey, Kang and Shaw, 1994). Sled test results will provide the baseline data to validate these simulations. The model will be used to examine the effects of different wheelchair back heights and stiffnesses.

Implications and Discussion

Transportation is becoming more accessible to mobility aid users due to the presence of special transport services and modifications to buses and privately owned vans. Therefore, it is important for wheelchair designers to consider the need for wheelchairs to protect the user in the event of a collision. It is unlikely that wheelchair backs have the same dynamic characteristics as automotive seat backs, but the question remains: do wheelchairs provide the same level of protection to the occupant in a crash environment? This research will only address the consequences of a rear collision. Further study is needed to examine the differences in safety that are involved with impacts in other orientations.

References

States, J.D. "Soft Tissue Injuries of the Neck." SAE Technical Paper #790135, 1979.

States, J.D., et al. "Injury Frequency and Head Restraint Effectiveness in Rear-End Impact Accidents." SAE Technical Paper #720967, 1972.

Data Link, Inc. "Current Issues of Occupant Protection in Car Rear Impacts" Prepared for the Office of Crashworthiness, Rulemaking, NHTSA, Docket 89-20-NO1-021, Data Link, Inc., Washington D.C., February, 1990.

Svensson, Mats Y. and Lovsund, P. "Rear-End Collisions: A Study of the Influence of Backrest Properties on Head-Neck Motion Using a New Dummy Neck." SAE Technical Paper #930343, 1993.

Viano, D.C. "Influence of Seatback Angle on Occupant Dynamics in Simulated Rear-End Impacts." SAE Technical Paper #922521, 1992.

Viano, D.C. "Restraint of a Belted or Unbelted Occupant by the Seat in Rear-End Impacts." SAE Technical Paper #922522, 1992.

Hohl, M. "Soft Tissue Injuries of the Neck in Automobile Accidents." Journal of Bone and Joint Surgery, Vol.56A: 1675-1682, 1974.

Mertz, H.J. and Patrick, L.M. "Investigation of the Kinematics and Kinetics of Whiplash." SAE Technical Paper #670919, 1967.

Severy, D.M., Brink, H.M. and Baird, J.D. "Rigid Seats with 28-inch Seatback Effectively Reduce Injuries in 30+ mph Rear-End Impacts" SAE Journal, SAE 69-532, Society of Automotive Engineers, Warrendale, PA, April, 1969

Pilkey, W.D., Kang, W., and Shaw, G. "Crash Response of Wheelchair-Occupant Systems in Transport." Proceedings of the RESNA 1994 Annual Conference, Nashville, pp. 61-63.

Walz, Felix H. "Biomechanical Aspects of Cervical Spine Injuries." Seminar on Cervical Spine Injuries, Oslo, June 3, 1994.

ECRI, "Positioning and Securing Riders With Disabilities and Their Mobility Aids in Transit Vehicles: Designing and Evaluation Program" Plymouth Meeting, PA, November, 1993, Prepared for Project ACTION, Washington D.C.

Red, E. et al. "Wheelchair Restraint Systems, Dynamic Test Results and the Development of Standards." 26th Stapp Car Crash Conference Proceedings, SAE Technical Paper 821161, 1982.

Acknowledgments

Special thanks go to Greg Shaw for providing me with the inspiration and motivation to perform this research. This research was sponsored in part by the National Institute for Disability and Rehabilitation Research (NIDRR).

Glenn Paskoff
Transportation Rehab. Engineering Center
UVA Auto Safety Lab
1011 Linden Ave.
Charlottesville, VA 22902
(804) 296 - 7288 phone
(804) 296 - 3453 fax

Change of Handling and Rollover Stability of Vans Due to Body Raise

Walter D. Pilkey, Weize Kang, Greg Shaw, and John G. Thacker
Transportation REC, University of Virginia
Charlottesville, VA 22903, U.S.A.

Abstract

Computer simulation and accident data analyses were used to study the effect of raising the body of a van on handling and rollover stability. Preliminary results suggest that a six inch body raise may result in unsafe handling characteristics in accident avoidance maneuvers and will increase the rollover rate.

Introduction

Modifications to passenger vans to accommodate disabled individuals may alter the structural integrity, directional or handling stability, and rollover stability of the vehicle. Currently, passenger vans are not required to meet any minimum standards for the dynamic stability. Vans with a separate body and frame structure have historically been the preferred vans for wheelchair-seated drivers because they are significantly easier and less costly to modify to accommodate the additional seated height of most wheelchair-seated drivers and to maintain the driver's field of vision. Raising the body will change the center of gravity (CG) height and mass moments of inertia of the vehicle, which in turns will affect the directional and rollover stabilities. In this paper, the CG height and mass moments of inertia of a modified van are estimated using the parallel axis theorem, based on the inertia parameters of the original equipment manufacturer (OEM) van obtained from the measured vehicle inertia parameter database [1] and laboratory measurements. The Vehicle Dynamic Analysis Nonlinear (VDANL) simulation program [2] was used to simulate the directional and rollover stability of an OEM van and a van with raised body under severe crash avoidance maneuvers. The vehicle dynamic responses, such as maximum lateral acceleration, maximum slip angle and roll angle, and normal load on each wheel, are compared. In addition, the static stability factors and the critical sliding velocities of the OEM and modified vans are calculated and are used to predict their single vehicle rollover accident rates (SVA) based on a regression analysis of rollover accidents[3]. Preliminary recommendations regarding a safe range of the body raise are presented.

Calculation of the Inertia Parameters of a Van with Raised Body

When considered as a dynamic system, a typical van consists of two parts, the sprung mass and the unsprung mass which are connected together by a suspension system. The sprung mass includes vehicle body and frame with engine and parts of the drivetrain attached on the frame. The unsprung mass includes the two axles and wheels. Figure 1 shows these masses and their CG positions, where M_{s1} represents the body, and M_{s2}, the frame. The M_u is the unsprung mass. The h_{s1}, h_{s2}, and h_u are the vertical heights of CGs of the body, frame, and unsprung mass, respectively. The h_s and h are the vertical heights of the CGs of the sprung mass and the whole vehicle, respectively.

If M_s is the total sprung mass, we define

$$\begin{aligned} M_{s1} &= \lambda M_s \\ M_{s2} &= (1-\lambda)M_s \end{aligned} \tag{1}$$

The percentage of total mass of the body, λ, can be obtained from the manufacturers, or estimated experimentally. For the van studied in this paper, we assume $\lambda = 0.6$.

From the parallel axis theorem, we have

$$M_s h_s = M_{s1}h_{s1} + M_{s2}h_{s2} \tag{2}$$

$$\begin{aligned} I_{xs} &= I_{s1} + M_{s1}(h_{s1} - h_s)^2 + I_{s2} \\ &\quad + M_{s2}(h_s - h_{s2})^2 \end{aligned} \tag{3}$$

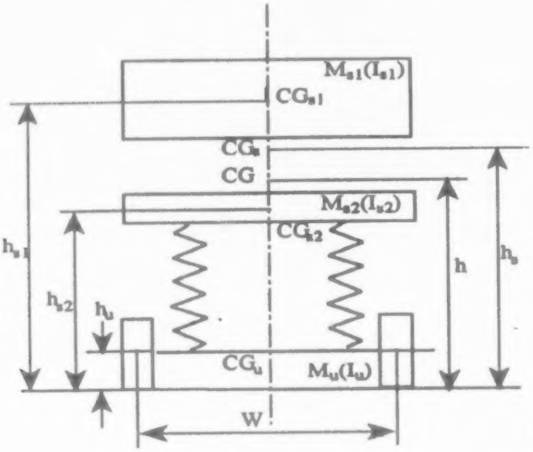


Figure 1: Vehicle masses and CG heights

where I_{s1} and I_{s2} are the rolling mass moments of inertia of the body and frame about the longitudinal axis through the individual CG, respectively. The I_{xs} is the rolling mass moment of inertia of the sprung mass about its CG. If the body is raised a height Δ, then the inertia parameters of the modified van can be found as

$$\begin{aligned} h'_s &= h_s + \lambda\Delta \qquad (4)\\ h'_s &= h + \frac{M_s}{M_s + M_u}\lambda\Delta \\ I'_{xs} &= I_{xs} + (1-\lambda)M_s[2(h_s - h_{s2}) + \lambda\Delta]\Delta \\ I'_{ys} &= I_{ys} + (1-\lambda)M_s[2(h_s - h_{s2}) + \lambda\Delta]\Delta \\ I'_{zs} &= I_{zs} \end{aligned}$$

where I_{ys} and I_{zs} are the pitch (transverse axis) and yaw (vertical axis) mass moments of inertia of the sprung mass about its CG, respectively.

Vehicle Dynamics Simulation

The VDANL simulation program was used to simulate the dynamic responses of the E150 van during the J-turn maneuver because J-turns can reveal the steady and transient responses of the vehicle. It is a pseudo-step input of the steering handwheel angle. Figure 2 shows the time history of the J-turn. The steering handwheel is turned rapidly at 600 degrees per second to a steady-state angle of 144.5 degrees. This steady-state angle produces a lateral acceleration of 0.7g for the OEM E150 van traveling at 80 km/h (50 mph), a severe crash avoidance maneuver.

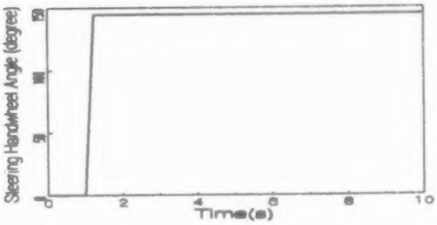


Figure 2: J-turn maneuver

The simulation shows that the maximum lateral acceleration, maximum slip angle, and the maximum rolling angle during the J-turn maneuver increase with the increase of the body raise. For example, with 6 inch body raise, the maximum lateral acceleration increases from 0.927g for the OEM van to 0.963g, the maximum slip angle, from 4.84° to 4.96°, and the maximum rolling angle, from 6.25° to 6.82°. During the turn, the normal loads on the inside wheels decrease, and the normal loads on the outside wheels increase. Figure 3 shows the normal load of the front inside wheel verses the amount of body raise. It can be seen that the load reaches zero with a 6 inch body raise. This means that the front inside wheel lifts off the ground during the maneuver. This may reduce the ability of the driver to control the van.

Rollover Stability Metrics and Rollover Propensity

The static stability factor (SSF) and the critical sliding velocity (CSV)[4] are used to predict the rollover propensity of the modified E150 vans. The SSF is defined as

$$SSF = \frac{W}{2h} \qquad (5)$$

where W is the track width of the vehicle, and h is the CG height of the vehicle (Fig. 1).

The CSV is defined as the minimum lateral velocity required to initiate rollover, when the vehicle is "tripped". This can occur when a vehicle that is sliding sideways contacts a curb. In this analysis the vehicle is considered a rigid body and the impact of the vehicle with the tripping object is assumed to be inelastic, that is, the coefficient of restitution is equal to zero. By equating the vehicle energy prior to the tripped impact with the energy needed to raise the vehicle CG to the point

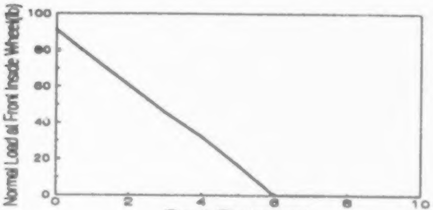


Figure 3: Normal load at the front inside wheel during J-turn

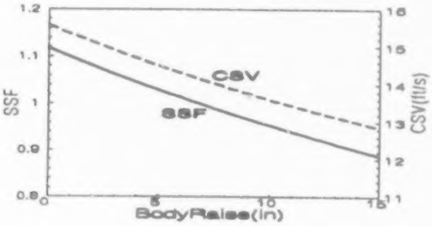


Figure 4: SSF and CSV verses body raise

where it is just above the pivot point about which the vehicle is rolling, it is found to be

$$CSV = \sqrt{\frac{2gI_{xo}}{h}\left[\sqrt{(1+\frac{W^2}{4h^2})}-1\right]} \quad (6)$$

$$I_{xo} = \frac{I_x}{M} + (h^2 + \frac{W^2}{4}) \quad (7)$$

where M is the total mass of the vehicle, and I_x is the rolling mass moment of inertia of the vehicle about its CG.

Because the body raise changes the CG height and the mass moments of inertia of the vehicle, it will change the SSF and CSV. Figure 4 shows the SSF and CSV as the functions of body raise height. A study of the accident records of 40 vehicle models [3] found the regression relations between the single vehicle rollover accident rate (SVA), e.g., the rollover per single vehicle accident rate, and both the SSF and CSV:

$$SVA(\%) = 133 - 62SSF - 0.35l(in.) \quad (8)$$

$$SVA(\%) = 103 - 5.25CSV(ft/sec)$$

where l is the vehicle wheelbase in inches.

With 6 inch body raise the rollover rate for the van studied in this paper will increase from 16.1% to 22.6 %, as predicted by the SSF, and from 21.1% to 27.9%, as predicted by the CSV. The range of the SVA for existing vans is between 12% and 25%.

Conclusions

Raising the body of a van will decrease the directional and rollover stabilities of the vehicle. Preliminary analysis suggests that a six inch body raise for the van studied in this paper will result in the front inside wheel lifting off the ground during a severe J-turn maneuver. A six inch body raise will also increase the rollover rate from approximately 21% to 28%. No major difference in the handling and rollover stability was found between the OEM van and the van with less than 6 inch body raise height. Thus, it is suggested that the body raise be limited under 6 inch for the modified van.

Acknowledgments

The National Institute on Disability and Rehabilitation Research (NIDRR) and the Virginia Center for Innovative Technology sponsored this research.

References

[1] Garrott, W. R., Measured Vehicle Inertial Parameters - NHTSA s Data Through September 1992 , SAE paper 930897, March, 1993.

[2] Allen, R. W., etc, Vehicle Dynamic Stability and Rollover, Report No. STI-TR-1268-1, System Technology, Inc., June, 1992.

[3] Mengert, P., S. Salvatore, et al., Statistical Estimation of Rollover Risk, U,S, Dept. of Trans. NHTSA, Report DOT-HS-807-446, Aug. 1989.

[4] Hinch, J., Shadle, S., and Klein, T. M., NHTSA's Rollover Rulemaking Program - Results of Testing and Analysis, SAE paper 920581, 1992.

Walter D. Pilkey, Morse Professor
Transportation REC, University of Virginia
1011 Linden Av.
Charlottesville, VA 22903, USA
Tele. (804)924-3291, Fax. (804) 982-2037
E-mail: wdp@virginia.edu

UNIVERSAL TIEDOWN AND OCCUPANT RESTRAINT SYSTEM FOR MOBILITY AIDS

Colin A. McLaurin, C. Gregory Shaw; University of Virginia, Charlottesville, VA
Donald R. Myers; Triangle Research and Development Corporation, Raleigh, NC

ABSTRACT

In response to the long expressed need for a universal system to safely secure wheelchair van and bus riders, an innovative wheelchair tiedown and occupant restraint system (WTORS) prototype has been developed that is crash safe, easy to use, and adaptable to commonly used mobility aids. The design has several advantages over one or more present systems including easier, more reliable operation and lighter hardware that can accommodate common lightweight folding wheelchairs. Further assessment and design refinements are required in order to produce a system suitable for universal application.

BACKGROUND

For more than 15 years, bus and paratransit operators, rehabilitation professionals, and transportation safety experts have supported the development of universal wheelchair tiedown and occupant restraint system (WTORS). The combination of a lack of national standards and a proliferation in the varieties of wheelchair and WTORS configurations has made it impossible to provide a consistent level of collision protection for passengers who ride seated in their wheelchairs. Passage of the Americans with Disabilities Act of 1990 (ADA), which made accessible public transit a civil right, and the proceeding transportation regulations (56 FR 45530), which provided the first significant national safety mandate, has added a new urgency to the search for a workable WTORS that can accommodate all common wheelchairs and mobility aids. Since the mid-1970s, state and federally supported research has been conducted to evaluate and to develop an improved WTORS [Dalrymple 1990, Schneider 1991]. From the start, researchers recommended a universal system [California 1974, Garland 1989].

Although crash testing has identified systems that offer a much greater level of safety than previous designs, no system to date has been proven to offer the required combination of superior occupant protection, convenient operation, and flexibility to accommodate different wheelchair types. The ideal system would combine the best features of existing systems namely the economy and universality of strap systems and the ease and independence of operation of docking systems.

OBJECTIVE

The goal of this development effort is to design and evaluate a new WTORS that offers the combination of features necessary for universal use with common wheelchairs and mobility aids.

APPROACH

A prototype, with an attachment method suitable for a common lightweight wheelchair, was developed and tested. Specific tasks included establishing design criteria, developing a computer model for use as a design tool, refining the proposed WTORS concept, constructing working prototypes, and conducting crashworthiness testing. Future work will involve conducting human factors testing with wheelchair users, caregivers, and transit personnel and working with manufacturers to develop the concept into a viable product compatible with a wide range of common wheelchairs and mobility aids.

DESIGN

Figure 1 shows the major elements for the tiedown subsystem. At this time, an independently mounted 3-point occupant restraint is used to complete the WTORS. The wheelchair-mounted hardware illustrated in figure 1 is appropriate for a standard configuration manual wheelchair. The element most critical to universality of the system is the transverse bar. Different wheelchair-mounted hardware may be required to acccommodate other mobility aid configurations. The design allows for the possibility of alternative capture mechanisms that could include below-floor installation.

The system consists of two parts, one which is fitted to the floor of the vehicle, the capture mechanism, and the other which is fitted to the mobility aid, the wheelchair hardware.

The capture mechanism consists of a metal plate with a hinged jaw. The mechanism is bolted to the floor of the vehicle. The plate with the hinged jaw is mounted in the vehicle with the open face of the jaw towards the rear of the vehicle and the hinge axis parallel to the floor and at right angles to the fore and aft axis of the vehicle. Parallel and in front of the hinge axis is a control rod which is connected to the jaw by a pair of links such that rotation of the rod causes the jaw to close with the linkage slightly past dead center. Rotation of the control rod in the

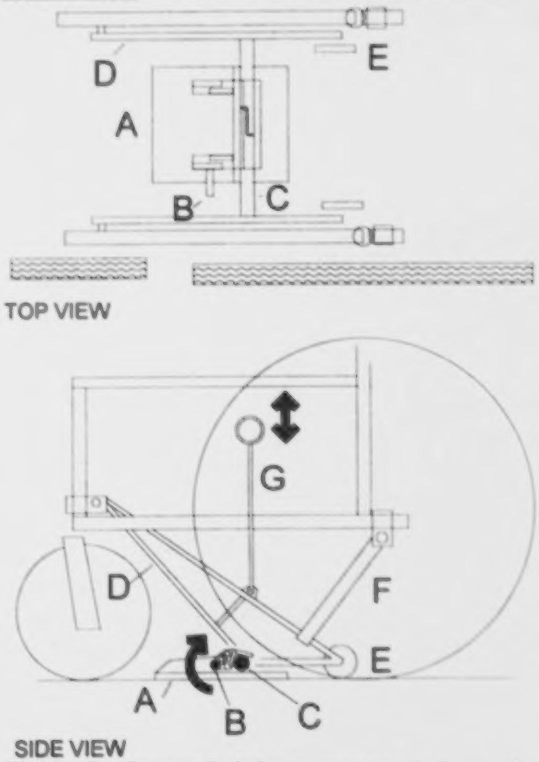


Figure 1. Proposed tiedown concept. A lap and shoulder belt was used to complete the wheelchair tiedown and occupant restraint system.

A - Vehicle-mounted capture mechanism.
B - Control rod. Rotation of the control rod activates and over-center linkage that clamps jaw over the transverse bar.
C - Transverse bar automatically engaged by capture mechanism when wheelchair rolls into place.
D - Truss members that hold the transverse bar attach inside wheelchair side frames.
E - Truss members contact floor behind the transverse bar to prevent the wheelchair from pitching backward.
F - Tension members attached to the rear of the wheelchair frame prevent forward tipping.
G - Linkage to lower the truss members and transverse bar to the floor for docking. The assembly is raised for increased ground clearance when not in the vehicle.

opposite direction causes the jaw to open. The jaw in the open position allows the transverse bar to move into or out of the jaw. The jaw, when closed, grips the bar, pulling it down and clamping it to the floor plate. Rotation of the control rod can either be accomplished manually with a right-angled lever or it can be electrically or hydraulically powered. The initial prototype capture mechanism uses a manual lever that is positioned so that it may be operated by the wheelchair passenger or by another person in the vehicle. The lever activation method and the required activation force has been selected to accommodate many wheelchair users with reduced manual dexterity and arm strength.

The wheelchair hardware can take many forms depending upon the design of the wheelchair, but the critical component is one with a one inch diameter bar mounted parallel to the floor with its axis at right angles to the fore and aft axis of the wheelchair. When deployed for clamping the bar rests on the floor and is brought into engagement with the jaw by forward motion of the wheelchair. For normal use, the bar is retracted upward to avoid striking obstacles. For folding wheelchairs, the bar is articulated with a double joint at its center which allows it to jackknife (fold) 180°. Note that the jaw of the capture mechanism prevents the bar from folding where it is engaged.

The truss members that locate the bar prevent forward motion of the wheelchair during deceleration. To prevent forward tipping of the wheelchair and to prevent rearward motion, two additional tension members which extend from the ends of the bar to points on the frame above and behind the bar. These members must be telescoping or flexible, such a straps or cables which allow the bar to be retracted upward when not deployed for clamping to the vehicle. Many means are possible to achieve the retraction. Lanyards attached to the bar or rods and extending upwards to the arm rests or to the back of the wheelchair are examples. The truss members extend behind the bar to contact the floor plate several inches behind the bar. The extension or foot acts as a lever to prevent the front of the wheelchair from rising during severe forward acceleration due to a rear impact or during the rebound from a sudden stop or crash. The truss members replace a simple tension beam design that did not provide control of wheelchair rebound movement.

EVALUATION

Three 30 mph frontal impact sled tests were conducted in accordance with test procedures proposed for the Society of Automotive Engineers (SAE) WTORS standard to evaluate the system's crashworthiness. A 165 lb anthropomorphic crash dummy was restrained by a lap and shoulder belt in each of the tests. Two tests were conducted with standard adult manual wheelchairs (a 42 lb E&J Premier 2 and a 41 lb Invacare 2000). The final test used the SAE test wheelchair that was designed to approximate a standard 187 lb powered chair.

The system consistently controlled forward wheelchair movement and prevented dangerous wheelchair deformation. Dummy forward movement was well within proposed SAE guidelines. After revision of the wheelchair hardware, the tendency of the wheelchair to pitch backwards was markedly reduced. The same capture mechanism, used in each of the tests, showed no signs of permanent deformation. After each test, the mechanism allowed release of the wheelchair with no increased effort.

DISCUSSION

Success in the early prototype stage has justified further refinement and evaluation of the concept. Although we were unsuccessful in eliminating the need for hardware to be attached to the mobility aid, the fundamental design has several advantages with respect to one or more of the currently available systems. Being a docking type system, the design is very convenient to use. Because of the system's geometry and points of attachment to the wheelchair, the number, weight, and visual impact of the required components are reduced. The low-profile capture mechanism is less likely to be a tripping hazard. The ability to fold the wheelchair is not compromised. The bar that is captured by the vehicle floor-mounted unit is lowered to the floor during docking. This ensures reliable vertical placement that is unaffected by tire inflation. The precise location also allows tighter tolerances in the vehicle-mounted unit providing good control of wheelchair movement during vehicle maneuvers. The system can be operated by hand - a potentially lower cost product - or by powered activation.

In addition to the crash test evaluation that the system successfully completed, future assessment will involve allowing mobility aid users, caregivers, and transit personnel to judge ease-of-use. The computer model will be used to simulate side and rear crash tests of the system. In its present form, the capture mechanism and wheelchair hardware are compatible with standard manual wheelchairs. We will survey a wide range of common mobility aids to confirm that there is sufficient ground clearance for the capture mechanism and that it is possible to design suitable wheelchair hardware. The assessment results will be used to develop an enhanced prototype. WTORS and mobility aid manufacturers will be consulted to explore the eventual commercialization of the system.

REFERENCES

Dalrymple, G.D., H. Hsia, C.L. Ragland, and F.B. Dickman (1990). Wheelchair and Occupant Restraint on School Buses, U.S. Dept. of Transportation, National Highway Traffic Safety Administration.

Garland, L., S. Dorion, and H. Vietinghoff (1989). Development of a Standard Interface for Securing Wheelchairs in Accessible Vehicles, TES Limited, Ottawa, Canada, Report No. C1076.

Schneider, L. (1991). Rationale, Historical Synopsis of the Literature, and Bibliography, Vol. 2, prepared for Canadian Standards Association of Ontario, Toronto, Canada, Document #R91-13.

Student Wheelchair Transportation - Loading and Securement, State of California business and Transportation Agency, Division of Mass Transportation, August 1974.

ACKNOWLEDGMENTS

This project is supported by the Triangle Research and Development Corporation through the US Department of Education SBIR Program, the National Institute for Disability and Rehabilitation Research, and the Virginia Center for Innovative Technology. Support has also been received from Invacare and Everest and Jennings. Prototype fabrication services were provided by UVA Biomedical Machine and Design's Bob Bryant. Crash testing was performed by the staff of the UVA Automobile Safety Laboratory.

Colin McLaurin, University of Virginia, Biomedical
Engineering Department, Box 346 HSC
Charlottesville, VA 22908
804-982-2548 ph., 804-982-2576 fax

Greg Shaw, University of Virginia Auto Safety Lab
1011 Linden Av.
Charlottesville, VA 22902
804-296-7288 ph., 804-296-3453 fax

Don Myers, Triangle Research and Development
Corp., POB 12696
Research Triangle Park, NC 27709
919-781-8148 ph., 919-781-8483 fax.

EVALUATION OF POWERED LIFTS FOR COMMUTER RAILCAR ACCESS

Ronald Gaal, Ray Grott, Norman Owen, Peter Pfaelzer
Engineering Design Center
San Francisco State University
San Francisco, CA

ABSTRACT

The Commuter Railcar Accessibility Study was conducted to guide the California Department of Transportation (Caltrans) in designing accessibility into existing and planned commuter railcars. Three different lift types and two lift locations were studied, as well as other accessibility issues; this paper highlights the lift evaluations. The study emphasized the consumer perspective, involving 53 people with disabilities in testing and evaluation of mock-up equipment. A set of design criteria for new and/or improved lifts was created, which expands upon the guidelines in the Americans with Disabilities Act (ADA). Many of the study's conclusions are also relevant to the accessibility of other rail systems, non-rail transportation, and buildings.

BACKGROUND

The California Department of Transportation, Caltrans, managed a railroad called the Peninsula Commute Service (PCS). Known also as CalTrain, the system operates along the San Francisco Peninsula. The Commuter Railcar Accessibility Study was conducted to pursue methods to make CalTrain railcars accessible to people with mobility impairments.

The research was undertaken to guide modifications of existing PCS railcars, and to impact the design of a new generation of accessible railcars. As well, many of the study's findings are relevant to the accessibility of other rail systems, non-rail transportation, and buildings.

Three different lift types and two lift locations were studied, as well as proposed restroom configurations, maneuverability of people using mobility devices inside the railcar, wheelchair tie-down area configurations, and other accessibility issues. This paper highlights the lift evaluations, drawing upon the 150-page final report that was prepared for Caltrans.

The study emphasized the consumer's perspective, involving 53 people with disabilities in testing and evaluation of equipment. The team consisted of engineering faculty and students, assisted by three subcontractors who specialized in accessible design, transportation planning, and railroad equipment and operations, respectively.

The specific objectives pertaining to lifts were:
1) to evaluate three different prototype lifts regarding safety, function, and user acceptance, and
2) to evaluate two lift placement locations--the vestibule and plug door. (The plug door is a removable section of the seating area wall.)

Currently the PCS railcars are accessible only to ambulatory riders. The outside doors open into a vestibule area at the midpoint of the car. Passengers enter from either side of the car by climbing up four steps to the vestibule floor level (roughly four feet above track level), then turning left or right to follow an aisle to the seating areas.

METHOD

Test Facilities

Test facilities featured a full-scale mock-up of the central portion of a PCS railcar, fitted with three prototype lifts.

Test Participants

Fifty-three test participants were recruited with attention to representing a breadth of both disability and mobility device types. There were 18 manual wheelchair users, 19 powered wheelchair users, and 16 powered scooter users. Eight participants also used canes, crutches, or walkers, and tested the lifts twice--once in their wheeled device and once on their feet. Most were familiar with lift use--68% rode busses and 42% private vans with lifts.

The Lifts

The three lifts evaluated, which we will refer to as the Folding Step lift, Under Step lift, and Through Wall lift, were manufactured by Nihon, Lift-U, and Ricon, respectively. The first two lifts were installed in vestibule stairways, and the Through Wall lift used the plug door. Please note that the three prototype lifts were tested and evaluated as delivered and installed on the railcar mockup by the manufacturers (or representatives), who made final adjustments and inspections. We will briefly describe each lift.

When stowed, the Folding Step lift forms steps along one half of the staircase located in the railcar vestibule. Upon deployment, the hinged step sections straighten out to form a platform.

The Under Step lift stows underneath the vestibule, behind the staircase. To deploy the lift, the platform slides out horizontally and then raises or lowers.

The Through Wall lift stows in a vertical position a few inches inside the passenger compartment at the plug door. To deploy, the lift platform first pivots down to a horizontal position, level with the railcar floor, then is lowered (and raised) on articulated arms.

All three lifts use electrically-powered hydraulic systems. All of the lift platforms have flaps, at the inboard and outboard edges, that pivot upwards to form safety barriers when the lift is in motion, and downwards to act as ramps or bridges to the ground or railcar floor.

Test Procedures

Test participants boarded and alighted to and from the mock-up railcar using each of the lifts. Testing staff operated the lifts and recorded the elapsed time during each segment of operation. Staffers carefully monitored safety. After riding all three lifts (in random order), each test participant answered multiple choice and narrative questions about his or her impressions of the lifts.

Additional information was gained via focus group discussions--one composed of test participants and another of current CalTrain passengers.

Data Analysis

Numerical data were compiled and analyzed using database and statistical software. Qualitative data were reduced by a multi-step process of grouping similar comments and creating weighted paraphrases.

RESULTS

Lift Operation Time

Although there was some variation between the lifts, it took an average of 60 to 90 seconds for a passenger to board the railcar, while alighting was slightly faster. Boarding took as long as three minutes for some passengers. Mechanical operating times vary between lifts, but human factors can overshadow mechanical ones. Type of mobility device was not a predictor of boarding time. Boarding times are expected to have a negligible effect on overall train scheduling.

User Preferences

The Under Step lift was preferred by 70% of users, because of its level platform, large end flaps, smooth operation, and good handrails. Twenty-one percent of consumers preferred the Through Wall lift. Many users liked its overall operation but received an unfavorable impression because the platform slams down when deployed, and most did not like the requirement to board sitting with their backs toward the train. The Folding Step lift was chosen by 9%; it was disliked for its jerky movement, steep slope when on the ground, and undersized inboard safety flap.

Preference regarding location of the lifts was equally divided between the vestibule and plug door locations.

Lift Location

The advantages of the vestibule location are the opportunity to board alongside a companion or service dog and other passengers, and greater headroom. The major disadvantages are the safety hazard posed to wheelchair riders by the open stairway on the opposite side of the car from the lift, and the difficulty of maneuvering to and from the lifts.

The plug door location offers direct access to the seating area, reducing maneuverability problems. Standing lift users, however, must crouch to walk under the upper-level seating. The major disadvantage to the plug door location is the loss of seating resulting from installation of the lifts in the passenger compartment.

Comparison of Lifts for Safety and Function

The data were used to develop lists of the favorable features, unfavorable features, and design deficiencies of each lift. These lists cannot be effectively summarized here.

RECOMMENDATIONS

1. Lift Location and Type

The plug door location was recommended for PCS railcars because of better maneuverability and because costly modifications to the vestibule would be needed to insure the safety of lifts located there.

All of the lifts tested would need modifications to become sufficiently safe and functional for use on PCS railcars. That said, we recommended a lift similar to the prototype Through Wall lift. Despite consumers' strong preference for the Under Step lift, project staff felt that reliability and the other proposed design criteria would be more easily met by a modified version of the Through Wall lift.

2. Design Criteria

We recommend that the design criteria developed in this study be used as the basis for new lift designs. The criteria specify the dimensions and slopes of lift platforms and end flaps, handrail height and length, headroom, cycle time, lift control safeguards, etc.

Not all of the proposed design criteria agree with ADA (1) and CHP (2) regulations. Where they differ, our proposed design criteria suggest larger dimensions and safer features as indicated by test results. The following partial list highlights these alternate criteria, plus many on which the cited regulations are silent:

Lift platform width: 32 inches, minimum, measured at platform surface. (ADA requires 28.5 inches at platform surface, increased to 30 inches measured at 2 to 30 inches above surface.)

Lift platform length: 60 inches, minimum, measured at heights of 6 or more inches above platform. (ADA requires 48 inches, measured at 2 to 30 inches high.)

Side edge height: 4 inches, minimum, for safety. (ADA requires 1.5 inches.)

End flap height and angle (as barriers): 10 inches high, minimum, and 45 degree angle from horizontal, minimum. (ADA not specific.)

Handrails: Length sufficient to be reached by seated or standing rider facing either direction. Cover with non-slip material.

Spotting rider on lift platform: Should not depend on operator assistance. Provide physical stops and visual and tactile cues. If end flaps used for spotting, mark for high visibility. Indicate safe location for standing riders as well as wheeled mobility users.

Headroom: Lift motion must not cause standing (or seated) rider to contact doorway; recommend optional fold-down seat for ambulatory riders.

Mobility device brakes: Safe lift operation should not depend on wheelchair or scooter's brakes being set.

Motion warning: Recommend providing sensory warning to indicate lift platform is about to move.

Backup operation: Lift should be stowable by one person, without special tools or excessive effort, in the event of electrical or mechanical failure.

Lift operation time: Mean cycle time of 60 seconds, maximum, including passenger movement on or off; 30 to 35 seconds for mechanical operation only (without passenger movement).

Lift controls: Simple and fail-safe; provide deadman feature; provide parallel controls inside and outside.

Propulsion means: Avoid use of hydraulic systems, known to be unreliable in the railroad environment.

3. Consumer Testing

Any new and/or improved lifts should be tested and evaluated in the existing mock-up, with input from a broad spectrum of disabled persons.

REFERENCES

1. Architectural and Transportation Barriers Compliance Board (1991). *Americans with Disabilities Act (ADA) Accessibility Guidelines for Transportation Vehicles*, 36 CFR Part 1192, Federal Register, Vol.56, No.173, pp.45529-81, September 6.

Department of Transportation (1991). *Americans with Disabilities Act (ADA) Accessibility Guidelines for Transportation Vehicles*, 49 CFR Part 38, Federal Register, Vol.56, No.173, pp.45756-78, September 6.

2. Department of the California Highway Patrol (1991). "Wheelchair Lifts," *California Code of Regulations*, Title 13, Division 2, Chapter 4, Article 15, Fiche Edition, UMI, Ann Arbor, Michigan.

ACKNOWLEDGEMENTS

This research was supported by the Rail Services Branch, District IV, of the California Department of Transportation. The authors gratefully acknowledge the guidance and contributions of Rebecca Shaffer, James Horton, Bhoopen Kurani and Paul Smith of Caltrans, Barry Atwood, Judy Jackson, and Peter Margen of Access Specialists, Inc., David Koffman of Crain & Associates, Inc., Michael Weinman of Passenger Transportation Specialists, Inc., and all of our assistants and test participants.

Ronald (Ronny) P. Gaal, P.E.
Wheeled Mobility Center
San Francisco State University
2746 Fulton Street
Berkeley, CA 94705-1032
(510) 849-3202

WHEELCHAIR USER STABILITY DURING SIMULATED DRIVING MANEUVERS

Thomas C. Adams, Steven I. Reger, Ph.D., Maureen A. Linden, Derek G. Kamper
The Cleveland Clinic Foundation, Department of Physical Medicine and Rehabilitation
Cleveland, OH, U.S.A.

Abstract

The stability of individuals seated in wheelchairs during driving maneuvers is difficult to measure consistently. Acceleration profiles of a large transit bus were measured on the floor at the wheelchair position during five severe driving maneuvers performed under test conditions. Simulation of these vehicle maneuvers was then performed in a laboratory environment, and the displacement of the test subject's center of gravity was measured relative to the wheelchair seat. It was shown that the center of gravity shifts in the direction of the simulated lateral acceleration with a human subject without trunk support, and with an anthropomorphic test dummy. The shift in the test dummy's center of gravity during the maximum acceleration was significantly less than that of the human subject. When the human subject uses trunk muscles alone or in combination with arm support to stabilize himself, the center of gravity is shifted in the opposite direction to the simulated lateral acceleration.

Background

The need for safe transportation of disabled travelers is widely recognized, yet relatively little attention has been paid to the comfort of individuals who travel while seated in wheelchairs. These individuals frequently lack trunk and arm strength for active stabilization, and their seats do not incorporate the passive stabilizing features of the vehicle seats, such as contouring, reclining back, and heavy padding. The stability of wheelchair users traveling in vehicles needs to be better understood and considered when prescribing seating systems and wheelchairs, recommending driver training for wheelchair users, and selecting and applying occupant restraint systems.

During controlled testing within a moving vehicle, turning maneuvers were observed to have a greater effect on a wheelchair user's stability than acceleration or braking activities.(1) As the vehicle turns, the centrifugal acceleration causes the passengers to experience a lateral inertial force. To maintain stability, the inertial forces must be opposed by passive body contact or active muscular contraction. Thus, the seating system and physiological condition should both be considered when assessing the stability of an individual traveling in a vehicle.

To evaluate the effect of seating variables on stability, reproducible test procedures are needed. Although driving maneuvers under controlled conditions have been shown to be highly reproducible, the availability of skilled drivers and adequate test courses are limited and expensive. To overcome these difficulties, laboratory equipment was designed and built to simulate the inertial forces experienced during driving maneuvers. A standard test dummy is proposed to remove subject specific bias from the data and produce generally applicable results with a minimum of testing.

To evaluate the feasibility of using a test dummy for stability evaluations, a 50th percentile anthropomorphic test dummy was used and it's response was compared to that of an able-bodied individual using various levels of muscular control for maintaining stability. This work will report on the similarity of the test dummy response to the response of the human wheelchair user, and the effect of different levels of muscular control on the stability of the individual.

Method

A 44 passenger transit bus was driven by a professional driver on a test course at the Transportation Research Center to determine the magnitude of the maximum centrifugal accelerations that could be consistently achieved. The bus could reproducibly achieve and maintain a speed of 19 mph while negotiating a turn with a 50 ft. radius, producing 0.5 g's of lateral acceleration.

This turning maneuver was found to have the greatest effect on stability, and was chosen as the worst case condition model for simulation. The lateral acceleration was simulated in the laboratory using a tilt-table. As the table and the wheelchair were tilted laterally, the weight developed a force component parallel to the table surface, simulating the horizontal force experienced by the traveler in the seat during the vehicle turning maneuvers. (Figure 1) In this configuration, the simulated lateral acceleration (in g's) is equivalent to the sine of the tilt angle, thus 0.5 g's was simulated with a tilt angle of 30 degrees.

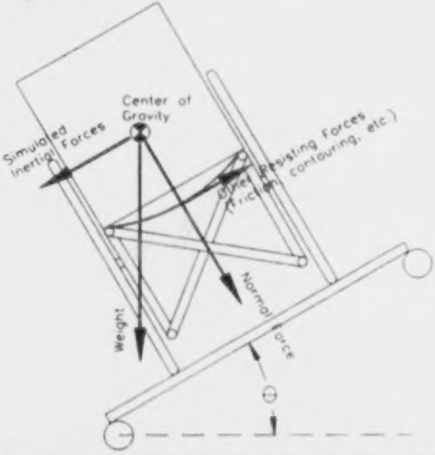

Center of Gravity
Simulated Inertial Forces
Direct Resisting Forces (friction, contouring, etc.)
Weight
Normal Force
Θ

Figure 1. Tilt-table mechanics generating lateral acceleration

A manual wheelchair frame was bolted to four load cells and mounted to the table. The seating system consisted of a three inch foam cushion adhered to a plywood board. The distribution of the forces on the load cells was used to determine the center of gravity of the test subjects in the horizontal (X-Y) plane relative to the wheelchair seat throughout the test. A triaxial accelerometer calibrated for angular displacement was mounted to the table and continuously recorded the tilt-angle. The accelerometer and load cells were interfaced with a Compaq 486 personal computer through a data acquisition board. Each channel on the board had a programmable gain allowing sampling with full resolution for inputs ranging from 0.01 to 10 volts. The analog to digital converter on the board had twelve bit resolution with a 3.3 microsecond conversion time.

Measurements were made using two test subjects, a Hybrid II crash test dummy representing a 50th percentile male (5' 8", 164 lbs.) and an able-bodied volunteer (6' 2", 175 lbs.) Each subject was positioned similarly with the foot restsadjusted to achieve good posture with horizontal thighs. Tests were run with the volunteer keeping his trunk muscles relaxed, using trunk muscles only for stability, and using his trunk, hands, and arm muscles for stability. Each configuration was repeated 3 times for analysis of variance on the data.

Results

Typical data is shown in Figure 2. From the graph, the test subject response can be divided into three segments; entering the turn (0.5 to 1.5 seconds), sustained lateral acceleration while turning (1.5 to 4 seconds), and exiting the turn (4 to 7 seconds). This paper deals with the response during the sustained acceleration, and at the end of exiting the turn. Future work will explore the significance of the displacements during phase 1.

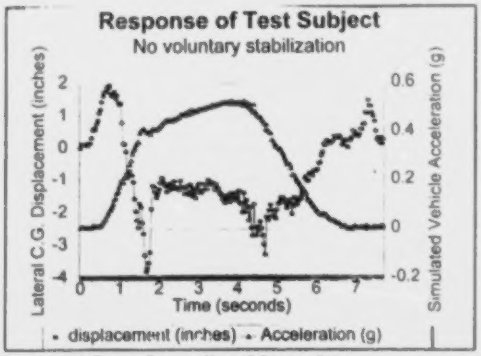


Figure 2. Data from tilt-table testing

The average displacement of the center of gravity was calculated over the time interval that the tilt table simulated a near constant 0.5 g's lateral acceleration. The center of gravity displacement was also measured at the end of the simulated maneuver. During the testing, there was motion of the center of gravity in both directions as shown in Table 1. The displacements are measured in the lateral direction, with positive displacement being in the direction of the simulated turn.

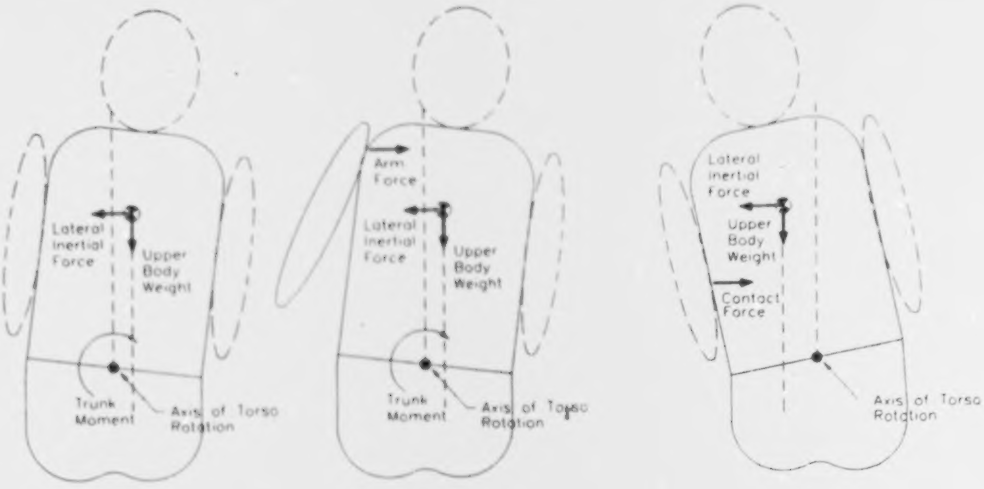
Discussion

The normal physiologic response to lateral forces on the body is to resist them using voluntary muscle control. In response to

Table 1. Center of Gravity Displacement

	Test Dummy	Human No Trunk Support	Human Trunk Support	Human Trunk and Hand Support
Displ. at .5 g (in.)	-.30 ± .10	-1.53±.29	1.27±.42	1.47±.23
Perm. Displ. (in.)	-.60 ± .17	-.07±.12	-.15±.13	.53±.31

BEST COPY AVAILABLE



a. Voluntary Trunk Stabilization b. Voluntary Trunk and Arm Stabilization c. No Voluntary Stabilization

Figure 3. Forces and moments affecting stability

centrifugal accelerations, this typically results in a shift of the center of gravity in the opposite direction to the force, often seen as "leaning into the curve". (Figure 3a,b.) The tilt-table simulation and center of gravity measurement have quantified this response for those tests where voluntary muscle control was allowed. When the arms are also used to present an opposing force, the center of gravity shift is approximately the same, as when the trunk muscles alone are used, indicating that through different mechanisms, the body achieves the same equilibrium condition.

Both the test dummy and the relaxed human without voluntary trunk muscle stabilization showed a shift in the center of gravity in the negative direction, indicating a falling into a secondary support such as the arm rest. (Figure 3c.) The test dummy therefore most closely models the human without voluntary trunk or upper limb muscle control.

The human subject, even without the voluntary use of trunk musculature tends to return to its initial position following the simulated maneuver, but the test dummy remains shifted. This may indicate that if a dummy is used to evaluate stability of a seating system, the information should be collected during the application of force when the dummy movement most closely simulates the human response. Additional testing is necessary to determine if the response of the relaxed able-bodied volunteer without voluntary trunk muscle stabilization is representative of individuals with true paralysis.The magnitude of the center of gravity shift through the simulated turning maneuver was small enough that it remained in the normal seated pressure region between the ischial tuberosities, indicating effective maintenance of stability through each mechanism. Thus the results of these simulation tests demonstrated close correlation to the in-vehicle wheelchair seated body response observed in the controlled motion tests conducted earlier.

Acknowledgments

The authors wish to acknowledge project funding through TCRP Project C-1, administered by the Transportation Research Board and through the Center for Automotive Research at the Ohio State University.

References

1. Reger SI, Adams TC, Sahgal V, Evaluation of Securement Systems during Severe Drivinng Maneuvers, Joint AAAM-IRCOBI Session, Advances in Occupant Restraint Technologies, 1994

Thomas C. Adams
Department of Physical Medicine and Rehabilitation
Cleveland Clinic Foundation
9500 Euclid Avenue
Cleveland, OH 44195 U.S.A.
(216) 445-9306

Securement of Wheelchairs in Motor Vehicles: Is It Time for a Universal Solution?

Douglas A. Hobson, Ph. D.
University of Pittsburgh, School of Health & Rehabilitation Sciences

Abstract

This paper discusses the multitude of issues involved in arriving at a universal solution to securement of wheeled mobility devices in motor vehicles. A proposal for the development of a universal interface standard that will integrate the involved technologies is made. A time schedule for completion of the work and a discussion of the unique window of opportunity that exists to successfully carry out this activity is also presented. The potential benefits to WMD users are outlined and a request for their participation if the process is also made.

Introduction

Increasing numbers of people with disabilities use wheeled mobility devices (WMDs), i.e., traditional manual and powered wheelchairs, powered bases, scooters, strollers, etc., as a means of accessing public and private motor vehicles. For many, the ability to use their WMD while riding in a transport vehicle is the only feasible means of gaining access to education, work or recreational activities. WMDs, both traditional and contemporary, were not designed to be used as seats in a transport vehicle. That is the wheels, seat and frame structures and battery containers were not engineered to withstand the high forces of a crash condition. Most WMDs do not have designated attachment points for securement to the vehicle, and therefore securement, both in terms of strength and location on the frame, can often be haphazard and uncertain from a safety viewpoint. Therefore, most WMDs do not provide the occupant the same level of rider safety as that provided by a car, van, bus or train seat for the non-disabled rider. However, the reality is that thousands of individuals are using untested WMDs on transportation systems on a daily basis. This creates a potential safety hazard for the WMD occupant, as well for other passengers in a transit vehicle in the event of a crash situation.

There are essentially two basic approaches to the securement of WMDs that are in common use today; attendant-operated and auto-engaged devices. The attendant-operated type is reflected largely by three or four belt-type devices that hook to various parts of the WMD frame. Problems arise when there is no appropriate location to attach the belt, for example, with scooters and some powered bases, the time required and the fact that an attendant must be present presents additional problems [Hunter-Zaworski, 1992]. Recent test results have indicated that existing belt systems are at the upper limits of their capacity when tested at 30 mph/20g loading [Fisher et al., 1987]. Heavier models of powered WMDs will not be secure at these crash load levels. Also, users of transit vehicles have expressed dissatisfaction with attendants having to grope around their legs while fastening or disengaging the securement devices.

Project Action (Accessible Community Transportation in Our Nation) conducted survey of 112 transit systems around the USA [Project Action, 1991]. The purpose was to identify general trends and problems with services for people with disabilities. Among the many findings the following are pertinent :

- about 50% of the systems have established target dates to provide full fixed route accessibility,
- the second most frequently reported problem is securing passengers using powered W/Cs or 3-wheeled scooters,
- most transit systems have not resolved the securement problem,
- the need for a safe securement system that can accommodate many types of W/Cs,
- the need for the W/C industry to establish standard securement attachment points, and
- the need for a universal securement device which can accommodate all types of WMDs.

As indicated by the above survey study, providing access on public transit vehicles for persons with disabilities is a well-established goal of most public transit agencies. However, the large diversity and styles of WMDs creates a problem for transit agencies due to the lack of standardized methods of securement. The need for "universal" securement also has been identified in several other survey's and state-of-the-art workshops [Brubaker et al., 1991; Hunter-Zaworski, 1992].

The WMD industry in North America is small compared to other major industries. The industry has met a very vital need for non-ambulatory individuals for many years. The first manual folding W/C was designed in 1933 by Everest and Jennings, with powered chairs following in the mid 1950s. Until recently most traditional W/C designs were based on the earlier E&J innovations. Now we have an ever increasing variety of WMDs including scooters, modified strollers, sports chairs, and powered bases. The industry has been an active participant in the development of the national performance standards for traditional wheelchairs.

Representatives from the industry have indicated that under present litigation laws and in the absence of a nationally recognized standard, it is untenable to market a WMD for transportation use. In fact, in 1992, the leading WMD manufacturers placed labels on their products specifically notifying users not to use them in transport vehicles.

A small number of manufacturers produce and market a range of occupant restraint and WMD securement devices. These are generally belt-type designs and are used routinely in school buses, para-transit and personal licensed vehicles to secure WMDs. Representatives from this industry have been participating as members of a multi-disciplinary Society for Automotive Engineers (SAE) task group to develop a national performance standard for restraint and securement devices. The first phase of this work is now essentially complete. Completion of the standard, followed by compliance by the securement industry, means that we now have a nationally recognized standard of securement and restraint device safety performance.

Public schools fall under federal legislation (PL. 92-142) which mandates that all children, regardless of mental or physical disability, are entitled to free and appropriate education. When determined necessary to accommodate the educational mandate, transportation must be provided as a related service. A significant percentage of children and young adults cannot transfer from their WMD to a regular bus seat and therefore must be transported in their WMD. In recent years there has been marked growth in the number of WMDs and specialized seating systems being used by children and young adults with disabilities. Essentially none of these devices have been developed and tested for use as a seat in a transport vehicle, as no standard exist against which testing can take place. Therefore, children are being transported in devices that are known to be unsafe for transport use.

On January 15, 1993, National Highway Transportation Safety Administration (NHTSA) published its final amendments to FMVSS-222—School Bus Passenger Seating

BEST COPY AVAILABLE

and Crash Protection [Federal Register, 1993]. Although representing a major step forward, the final requirements fall short in several important aspects. First, the rules only apply to the securement and occupant restraint devices leaving the safety issues involving the WMD totally unresolved. Secondly, the requirements require only static testing of securement and restraint devices; which fails to acknowledge the need to conduct dynamic tests which appropriately simulate the dynamics of a crash condition.

The recent Americans with Disabilities Act (ADA) requires that all fixed route transit vehicles be accessible. The ADA definition of accessibility requires that mobility aids "in common use" must be able to both get on to the vehicle and be secured once on board [ATBCB, 1992]. Since the WMD securement devices in common use today are four belt-type devices, this means that an attendant is required every time a person using a wheelchair wishes to access a public vehicle—an untenable situation. Any existing auto-engage docking devices in public vehicles are designed to grapple onto parts of the WMD that are neither designed as securement attachment points or require the assistance of an attendant.

Other methods of securement used are wheel or frame clamps which usually require an attendant, and in many cases pose an even greater concern for occupant safety in a crash condition [Schneider, 1981].

In summary, the transportation of WMD users in North America is in a state of chaos. The manifestations are that users are inconvenienced, transportation time and costs are unnecessarily high, legal liabilities are pervasive, and most importantly, user safety in many cases is seriously compromised. The ADA mandate of accessibility and safety, although laudatory in its intent, is technically unachievable until some fundamental systems issues are resolved.

Given today's technology, and the precedence that have been established in many other technology fields, it is a reasonable and an achievable goal to allow any person using any WMD access to any transport vehicle, with the safety and independence equivalent to non-disabled riders.

Towards Partial Solutions

As suggested above, the essence of the problem is that there are at least four industries involved: WMD manufacturers, restraint and securement system manufacturers, transportation systems, and transport vehicle manufacturers. These multiple entities have never come to any agreement on a standard for interfacing the WMD-related technologies produced by each of the industries until most recently for belt-type hardware. A well known example of this occurrence is in the national and international trucking industry. Virtually any tractor unit can hook-up to any trailer unit anywhere in the North America, simply because the tractor and trailer manufacturers have come to an agreement on the design standards for the universal interface hardware. That is, a universal solution that meets the needs of both industries and therefore the needs of their customers. We have yet to define a universal interface for docking or auto-engage securemnent hardware, in which lies the key to a universal solution for WMD users.

Several auto-engage devices are commercially available. These devices have male and female components; one clamped to the W/C frame and the other to the vehicle [Hunter-Zaworski, 1992]. These can offer increased user independence, but again rely on having a location on the WMD to which one component of the securement system can be attached. Most WMDs do not have the appropriate securement attachment locations. Also, since there is such variety of WMDs, this necessitates a large number of securement configurations, each of which will need to be safety tested. Therefore, auto-engage devices can work reasonably well for private vehicles in which matching setups can be configured. However, present designs do not provide a generalized solution to the public transit problem. These early devices do represent a departure from the four-belt approach toward auto-docking devices, which is the first step towards a universal solution.

The Standards Approach

A unique opportunity exists to identify and implement a universal solution. Voluntary standards, both national and international, are being developed for WMD occupant and restraint systems. These efforts, which began in the mid 80's, have very recently resulted in a voluntary national standard for wheelchair tiedown and occupant restraint systems [SAE, 1995]. This standard is essentially identical to the standard being adopted by the International Standards Organization [ISO, 1995]. Although these initial restraint and tiedown standards primarily address the performance testing of four-belt designs, they have established the precedence and forum for the next step, a universal interface standard for auto-engage devices.

More recently, an ANSI/RESNA subcommittee has been working closely with ISO in the development of a compatible transport WMD standard. For the first time this work has brought together WMD users, WMD manufacturers, restraint/tiedown manufacturers, researchers and representatives from the transportation and vehicle manufacturing industries.

Both these developments create an important opportunity to tackle the fundamental obstacle to universal accessibility, the development and adoption of a universal interface standard for auto-engage devices.

The Universal Interface Proposal

Many examples can be found in which technologies from several industries have been compatibly interfaced for the ultimate benefit of the end user. The concept is simple. Agreement is reached on a standardized design of the interface that will allow the technologies to interconnect, than each industry designs and manufactures it's component to the agreed upon design standard. For example, if one has a 2" diameter ball on the trailer hitch on your private vehicle it means you can drive into any trailer rental lot in the country and hook-up and drive away with any trailer. Also, chances are good that the connectors for the rear turning signal and brake lights will also be compatible. This works because agreement has been reached on the configuration of the interface, in this case a 2" diameter spherical ball with a 3/4" diameter stem, that will withstand a horizontal load of 'x' lbs., etc. Similar agreement is required in the WMD/restraints/tiedown/vehicle fields if the ultimate goal of providing universal access to WMD users is to be achieved. Figure 1 schematically illustrates the universal interface concept.

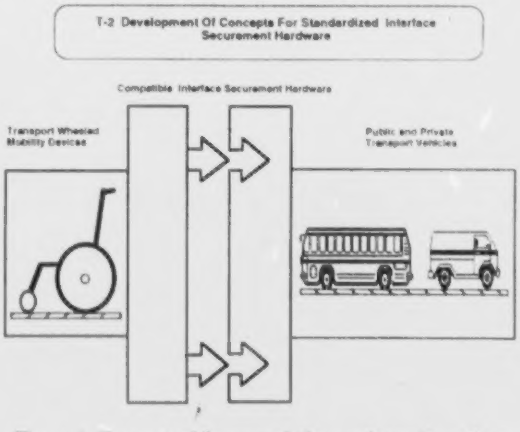

T-2 Development Of Concepts For Standardized Interface Securement Hardware
Compatible Interface Securement Hardware
Transport Wheeled Mobility Devices
Public and Private Transport Vehicles

Figure 1 Conceptual framework for a universal interface standard

BEST COPY AVAILABLE

The Resources and Development Process

Gaining consensus that involves interests of multiple industries, WMD users, regulatory agencies, researchers and the general public is a significant undertaking. However, as indicated above the nucleus of the players are already assembled under the auspices of ANSI/RESNA, the SAE and the ISO standards development committees, all currently chaired by the author. Added to this are the experiences and initial results of several researchers (Hunter-Zaworski, Adams/Reger, and McClaurin) who have designed and tested various types of auto-engage devices. The RERC on Wheelchair Mobility at the University of Pittsburgh has a major commitment to provide research support, and present draft criteria and working prototypes that could form the basis for the universal interface design. About 50% of the financial support has been committed for the development of the transport wheelchair standard by the ANSI/RESNA Subcommittee on Wheelchairs and Transportation (SOWHAT). There are several manufacturers currently committed to the manufacture and marketing of auto-engage securement devices. Finally, early indications are that if a universal interface standard can be developed and nationally adopted, leaders in WMD industry would be willing to add a securement point to the WMD, providing it does not unduly add weight or detract from the esthetics of their products.

Given the tremendous opportunity that exits, and the urgent need for a universal solution to the WMD securement problem, agreement could be reached in the USA on the criteria and design requirements for the universal interface within 12 months. A further 12 months will be required to validate the criteria and come to agreement on a design standard. An additional 12 months will be required to have the results adopted in an ANSI/RESNA standard and stimulate similar results at the ISO level.

The Potential Outcomes

Assuming adoption of a voluntary universal interface standard as proposed above, and the subsequent manufacturer and marketing of securement systems and WMDs that meet the standard, the following are potential outcomes that could be available to WMD users and transporters within five years:

- a much higher level of independence, privacy and safety for individuals wishing to use WMD securement in public and private vehicles,
- a significant reduction in attendant time due to the substitution of auto-engage devices for belt systems currently used in school buses and paratransit vehicles,
- elimination of the uncertainty by vehicle drivers as to how and where the WMD should be secured in the vehicle, and
- the real potential that over time any person using any WMD manufactured to the standard will be able to be self-secured in any public vehicle or private vehicle equipped for WMD transport.

The short term potential risk is that until products are widely available that are manufactured to the standards, unscrupulous transportation authorities could conceivably use the lack of such devices as the rationale for denying people access to public vehicles. However, it does seem that this would be inconsistent with the intent of ADA and IDEA and the legal recourse could be used to resolve the issue.

Summary and Conclusions

This paper has presented an overview of the many of the complex issues confronting WMD users, the multiple involved industries, and regulatory agencies involved in providing safe and independent securement of the WMD as a seat in a motor vehicle. The argument was made that agreement must be reached on the design criteria for a universal interface standard for auto-engage devices, which would then be adopted industry-wide as the design standard for the interconnecting hardware, if this complex problem is to ever be resolved. The current window of opportunity that exists and resources available were summarized. A development plan was suggested and the potential benefits for WMD users and the involved industries were outlined. It is requested that those WMD users and others concerned about this issue will help develop the ideas, designs, momentum and consensus necessary to move this problem towards a workable solution. Suggestions sent to the author will be brought forth to the various design and standards development groups. Requests for participation on the standards development groups are also most welcome.

Due to space limitations the issues related to interfacing of occupant restraint hardware was not addressed. This issue must also be resolved in parallel, since occupant restraint and WMD securement is a systems problem and therefore each component can not be adequately addressed in isolation.

References

Architectural and Transportation Barriers Compliance Board (ATBCB), (1991), American with Disabilities Act (ADA) Accessibility Guidelines for Transportation Vehicles, " 36 CFR Part 1192, Federal Register Vol. 56, No. 173, September.

Brubaker, C., Digges,K., Sprigle,S, and Thacker, J (1991) Transportation I, State of the Art Conference on Personal Transportation for Persons with Disabilities, Charlottesville, Virginia.

Federal Register, Rules and Regulations, (1993) United States Government, Vol 58, No 10, pp. 2 - 14, January 15.

Fisher, W.E., Seeger, B.R. and Svensson, N.L. (1987) "Development of an Australian standard for W/C occupant restraint assemblies for motor vehicles." Journal of Rehabilitation Research and Development, 24:3, pp. 23-34.

Hunter-Zaworski, K.M. (1992) Application of Quality Functional Deployment Method in Mobility Aid Securement Design-Volume I, National Technical Information Service, Springfield, VA, FT-OR-11-0006-92-1.

ISO, January [1995] CD 10452-1: Wheelchair tiedown and occupant restrint systems for motor vehicles.

Project ACTION, June [1990], Reconnaissance Survey of Selected Transit Agencies, Washington, DC.

SAE, January [1995] CD J2249 Wheelchair tiedown and occupant restriant systems for use in motor vehicles.

Schneider, L. (1981). "Dynamic testing of restraint systems and tie-downs for use with vehicle occupants seated in powered W/Cs. Final Report no. UM-HSRI 81-18. The University of Michigan, Highway Safety Research Institute, Ann Arbor, MI.

Acknowledgement

This work is supported by Grant # H133E30005 provided by the National Institute on Disability and Rehabilitation Research. Opinions expressed are those of the author and should not be construed to represent opinions or policies of NIDRR.

Addresss:

University of Pittsburgh, SHRS

UPARC

915 William Pitt Way

Pittsburgh, 15238, USA.

SIG-03
Augmentative & Alternative Communication

REACHING FOR THE STARS: A THEATER EXPERIENCE

Rena M. Carney, M.S., Actor's Equity
Prentke Romich Company
Catherine George, M.A., CCC-SLP
Assistive Technology Educational Network of Florida, Orlando, FL

ABSTRACT

Opportunities to participate in theater and performance based activities are rare for young adults using augmentative communication systems (AAC). It is the unfortunate case that many group communication opportunities are simply academic, rote or unimaginative. In order to provide an opportunity for the study of and participation in professional theater, "Reaching for the Stars," a four day theater workshop, was hosted at the Hippodrome State Theater in Gainesville, Florida in July, 1994. Theater, language, and technology goals culminated in the performance of a RIP-ROARING one hour "Saturday Night Live" type production. The actors used augmentative communication systems to communicate and perform, and electric wheelchairs to move and dance.

BACKGROUND

The desire to perform roars in the blood of many of us. Theater is an ancient religious and communication art form. Many people using AAC devices to communicate feel the same intense desire to wax poetic, orate or joke. In an effort to provide the opportunity for young adults using AAC systems to study theater and perform in a professional theater environment, a pilot theater workshop was presented at the State Theater of Florida .

Due to a limited amount of rehearsal time the script was written in advance. Literature on storytelling and the effects of technology in storytelling were researched (Stuart, 1993, Parks, 1994), as was literature on conversational competence of young adults who use devices to communicate (Davies and Atkinson, 1994). Williams and Baker's (1994) work on 'the art of chatting' was embraced as was Smith's (1985) work on metaphors for literacy.

The pre-planning stage of the workshop was initially divided into two major areas, the script and the coordination of the workshop. The theater director concentrated fforts on theater goals, writing the script, technical aspects of play production, the acting curriculum and working as liaison with the professional theater staff, guest artists and technical support staff. The workshop director concentrated efforts on language and technology goals and on other workshop elements including: accommodations (accessibility and availability), advertising, scholarships, budget, food, receptions, scheduling, device programming, video-vignettes, and co-ordinating the schedules of actors, staff and volunteers.

OBJECTIVES

THEATER OBJECTIVES:
Given a professional theater environment, cast members will participate in theater instruction and performance, taught by professional actors, in the following areas: stage direction, characterization, power of voice, choreography, music, and technical theater. Cast members will perform a one hour show, comprised of five vignettes that demonstrate the mastery of these skills.

COMMUNICATION OBJECTIVES:
Given a theater environment with both structured and unstructured social activities, cast members will:

- Interact with other augmented communication users: initiating and maintaining conversations, repairing communication breakdowns, asking for information, chatting, and shooting the breeze.
- Experience meaningful practice and use of AAC device operations and functions.
- Use communication devices to perform in a play: project lines, time delivery, use symbols for lines and cues, and extemporaneous speech.
- Use whole body language to project feelings and emotions in character.

TECHNOLOGY OBJECTIVES:
Given a performance oriented theater environment, cast members will:

- Use communication systems to their maximum's potential.

110

- Use a variety of communication systems.
- Observe and compare the effectiveness of a variety of communication systems used by peers.
- Shift to a backup system when device breakdowns occur.

APPROACH

BREAKING THE ICE AND TRUST

Trust exercises and games were played at the theater as the participants, volunteers and staff arrived.

SHADOWS

The first evening of the workshop "Shadows" were assigned. "Shadows" are familiar characters to people who have seen performances for deaf audiences. An actor, dressed in black, stands behind the hearing performer and signs whatever he/she may be saying. In "Reaching for the Stars" shadows were a key factor in the success of the production. Dressed in black, they merged with their actor, performed stage actions such as throwing spitballs and delivering love notes, assisted in blocking and script cues, and assisted the actors while rehearsing and performing.

LESSONS

All lessons were taught by professional actors and scholars. The instruction was applied to the actual vignette the actor was rehearsing and performing.

THE SCRIPT

"Reaching for the Stars," was written and produced with "typical teenage punk humor" in mind. A stand-up or "Saturday Night Live" format was deemed the best format given time, technology and theoretical considerations.

Other considerations affected the actual content of the script. Of particular concern was the audience. The audience would be a typical theater audience being exposed for the first time to young adults with severe physical challenges who use the cutting edge of rehabiliation technology. Shakespeare often used a play within a play scheme to educate the audience about what action was to come. This ploy was used in the "Stars" script. Five scenes or vignettes were written. Each was introduced by a mini-vignette "At the Bus Stop" which predicted the action to come. Content of the play included a history of the AAC movement, a spoof of technology in a"Conehead" bar, video vignettes (home movies on the big screen), Shakespearean rhetoric, and country western line dancing.

TECHNOLOGY AND LANGUAGE

Assessing and combining technology and language needs of each individual actor was an involved process. What communication system were they using? Was there a back-up? What system did they prefer? What system would be best for the performance? How should parts and lines be organized for easy access, memory for retrieval, and natural line delivery? Technology and language needs were addressed on an ongoing basis. Different devices were used within scenes, with the actual performance as the final consideration for which device should be used. Technology took a back seat to communication and a real partnership was noted between all technologies. The power of the voice was constantly analyzed as actors strove to produce natural sounding speech, English accents, robotic speech, and laughter.

DISCUSSION

Analysis of theater production goals indicates that all the time and preparation worked! Actors performed with great passion and skill. They remembered their blocking, cues, lines and characterization. They loved the show and the audience loved them. Audience survey indicates the audience was enraptured by the content of the play as well as the expertise of the actors.

Analysis of group conversational competence indicates that willingness to talk by young actors improved as actors felt 'safe' or motivated enough to communicate. Offstage communication was as important as onstage communication. Formal skills were learned which transferred to informal situations-what Michael Williams (1993) refers to as 'water-cooler culture.'

Analysis of storytelling and the effects of technology on storytelling indicates that vignettes were successful in this pilot attempt to produce a funny play couched in disabilities but not really about disabilities, rather, about communication, celebration, and laughter.

ACKNOWLEDGEMENTS

Funding for this project was provided by Prentke Romich Company, Sentient Systems Technology, Inc., Adaptive Consulting Services, The Hippodrome State Theater, and the Assistive Technology Educational Network of Florida.

Catherine George
A.T.E.N.
434 N. Tampa Avenue
Orlando, FL 32805
(407) 849-3504 Fax (407) 849-3518

JustType™ - Efficient Communication with Eight Keys

Martin T. King[1], Clifford A. Kushler[2], and Dale A. Grover[3]
[1] Vashon Able, Vashon, WA; [2] Prentke Romich Co., Wooster, OH; [3] Red Cedar Electronics, Lansing, MI

ABSTRACT

Many people who rely on augmentative and alternative communication (AAC) devices would benefit from a reduction in the number of cells in the selection matrix (e.g., a keyboard with fewer keys). One approach is to assign more than one letter to each key, using disambiguation techniques to determine what text to generate for a particular key sequence. Although many researchers have examined disambiguation techniques, this paper discusses enhancements which may result in increased communication efficiencies. Preliminary results show a keystroke efficiency of approximately 1.01 keystrokes per output character from a keyboard having eight keys. The development of a commercial system called JustType™ is discussed.

BACKGROUND

AAC users usually employ an input matrix or symbol set containing many elements. For spelling-based systems in English, the number of symbols is at least twenty-six. For icon-based communication systems the number of symbols often reaches a hundred or more. Many strategies have evolved for helping people who have limited motor skills cope with a large numbers of symbols or selection items. Large-scale keyboards, keyguards, electronic scanning devices, voice activation, and several other methods can be used to access large symbol sets.

An alternative approach is to reduce the number of selection items by allowing each cell or key to contain more than one symbol. Input from the user is now ambiguous (since each key has several meanings), but this ambiguity can be resolved manually by the user, or automatically by the communication device itself (see [1] for a review of the research on disambiguation).

A reduction in the number of selection cells can have important benefits. For individuals who already use a direct selection technique, using fewer cells allows larger individual keys and/or faster selections. For users of scanning techniques, fewer cells means that scanning proceeds more rapidly. In some cases a keyboard having fewer keys may allow direct selection by individuals who previously required a scanning technique. Moreover, voice-activated systems are more robust when fewer sounds must be recognized.

Research on automatic disambiguation has focused on two strategies, letter-by-letter disambiguation and word-level disambiguation. In the letter-by-letter approach, the system tries to disambiguate each key or cell as it is entered. Statistical analysis of "n-grams" (groups of n letters) is usually the predictive basis for these systems. One advantage of this approach is that the number of n-grams is relatively small, so storage/memory requirements are also small. A disadvantage of letter-by-letter disambiguation is that the user's attention is required as each key is entered.

In word-level disambiguation, user input is interpreted as complete words. The predictive basis for a word-level system is a dictionary of words and their relative frequencies. To be effective, this approach requires that all possible words be present in the dictionary; so storage requirements are larger than for the letter-by-letter approach. On the other hand, with word-level disambiguation the user's attention is only required at word boundaries, so the cognitive load is reduced.

The primary concerns with any disambiguation strategy are to minimize the cognitive load on the user, and to provide reasonable efficiency (often measured as keystrokes required per character output). Our work suggests that both of these goals are best met by a word-level approach. A sample keyboard developed for word-level disambiguation is shown in figure 1.

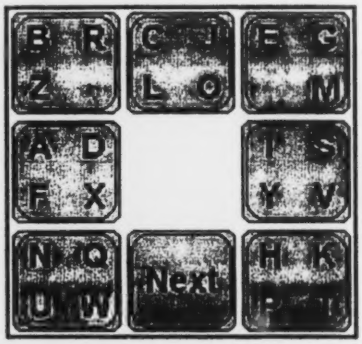


Figure 1. JustType™ eight-key keyboard.

BEST COPY AVAILABLE

STATEMENT OF THE PROBLEM

Our motivation for developing a disambiguation system was to implement a reduced keyboard for two commercial products, a simple eye-gaze device which recognizes eight eye positions, and general purpose input software called JustType™ for one-hand typing, head pointing, and joystick input.

The geometry of eight cells lends itself naturally to use with joysticks, or any physiological movement in two dimensions. In addition, having only eight cells means that any cell can be represented numerically by three bits.

Word-level disambiguation is a powerful AAC tool which seems to have been largely ignored. Prior researchers[2] have described systems which achieve greater than 96% correct output, yet we are not aware of any commercially available devices employing this technology.

Early researchers were perhaps discouraged by the amount of storage word-level disambiguation requires (about one megabyte for a very complete dictionary). However, with the falling cost of computer memory, this is no longer an obstacle.

Perhaps another reason this technique has been overlooked is that several early researchers focused on using touch-tone telephone keypads for input. These are not optimized for this application, and do not provide the feedback necessary for users to decide among ambiguous words.

RATIONALE

Word-level disambiguation only requires the user to interact at word boundaries (if then). This has significant benefits, especially for certain types of input devices and for those who need to devote more attention to motor tasks. In addition, word-level disambiguation is able to make use of more underlying information, making higher keystroke efficiencies possible. Thus, word-level disambiguation, rather than letter-level, seems to be a more beneficial approach. The storage requirements for a large word list are no longer impractical for a portable or desktop communication aid. Our goal has been to develop enhancements to increase user communication rates without placing an undue burden on the user.

DESIGN / DEVELOPMENT

Software has been developed that searches for the letter arrangement which minimizes the total number of ambiguities, taking word frequency into account. Using an eight key layout with an extensive vocabulary, about two-thirds of all words are unambiguous. Word frequency information also allows the system to present the most likely word as the default choice when ambiguities do occur. This process of providing an automatic default choice was used by other researchers in letter-level disambiguation.

In the eight key system described here, seven keys contain either three or four letters. The eighth key is the space key, or, more accurately, the "next" key. After each keystroke, the system displays the word or words that correspond to the key sequence up to that point. When ambiguities occur, the most probable word (the default choice) appears at the top of the selection list. Hitting the "next" key once selects and highlights the first word in the list. The user may then continue typing (the next key having acted as a space key), or continue to activate the next key to advance the highlight and select subsequent words in the list.

JustType™ allows the use of custom vocabularies and user-defined words. Custom vocabularies can include technical words specific to a particular context, such as medical terminology or geographical place-names. New words (not yet present in the dictionary) may be typed at any time by hitting two keys per letter: the first for the cell containing the letter, and the second to indicate which letter is desired by selecting the corner cell that corresponds to the desired letter's position in the first cell. This mode is always active. A system mode can also be used to enter punctuation, numerals, etc., for a minor penalty in additional keystrokes.

An important strategy in minimizing cognitive load for the user is to provide a consistent, predictable interface. To this end, the system never changes the order in which words are presented unless the user specifically requests it. This consistency, plus the fact that most common words are presented as default choices, means that entering text with JustType can be easily learned and rapidly becomes a rote task.

For users unable to directly select from a large number of cells, reducing the number of cells in the selection matrix from 26 or more to only 8 has important implications. For scanning techniques, rates may increase by a factor of two or more. Furthermore, the operator's attention seldom needs to be diverted from the scanning task. In those cases where alternate choices need to be selected for ambiguous key sequences, JustType can be configured such that, once the "next" key is selected, repeated activations are automatically generated at fixed intervals as long as the selection switch is depressed. Similar advantages result for "Morse code" type systems, since the average code length can be reduced to two.

EVALUATION

JustType has been implemented as a Windows application, and has been used with a mouse, a headpointing system, an expanded keyboard, and the prototype eye-gaze device. It has been informally tested by a number of able-bodied individuals and was found to be simple, fast and intuitive.

JustType was used to generate a recent draft of this paper. Although, as described above, punctuation can be generated with a small keystroke penalty, it is often omitted in conversation, so the statistics are generated for the text only. Proper nouns and abbreviations not in the dictionary (which would have been entered using the two-keystrokes-per-letter method) were ignored. 97.3% of the words appeared as the default choice and required no additional keystrokes. Of 1987 words, 44 appeared as the second choice and 9 as the third choice, requiring a total of 62 additional keystrokes to resolve all ambiguities. This is a total of 12,276 keystrokes for 12,214 letters and spaces, equivalent to 1.0051 keystrokes per letter.

DISCUSSION

One obvious constraint on the use of JustType is the requirement that the operator must have adequate spelling skills. A second drawback is that there is no way for the user to know when a mistake is made in selecting a key (i.e. an accessing rather than a spelling error) until the end of the word, at which time the desired word simply fails to appear. In most cases, it is reasonable to expect that only one such error occurred, and that it involved striking one of the two keys adjacent to the intended key. It may be possible to implement an error recovery scheme by augmenting the list of words disambiguated from each key sequence by those words that would result from such single-key errors when those words also occur with a high frequency (exceeding a pre-set threshold). Another approach is to wait until an entire message has been typed, then automatically scan through the words generated to deal with any errors or ambiguities in an appropriate editing mode. Another constraint is that the system must have sufficient memory for the required dictionary (about one megabyte).

On the other hand, there are a number of significant advantages to JustType for users who have the requisite spelling skills. One is the low cognitive load in learning and using the system. Experience with a number of individuals indicates that little time is needed to learn the arrangement of letters on the keys, or to learn how to access punctuation or basic system functions. Perhaps more significantly, most users quickly learned that common words would appear as the default choice, so that they only occasionally needed to check whether the default choice was the word desired. The incorporation of word frequency data in the system is crucial to the high efficiency rates achieved.

Other features to enhance JustType have also been developed. Many longer words become unambiguous before their last letters are entered. These words are immediately offered as the default choice, with an optional tone to alert the user.

Our preliminary results indicate that reduced keyboard strategies offer potential for AAC users, and that enhancements are possible which increase efficiency without additional burden on the user. For some individuals with the requisite spelling skills, JustType may be preferable to systems that require fewer selections but use a much larger selection matrix, and which generally involve much larger cognitive and perceptual loads.

Some ideas discussed in this paper are the subject of a patent application by the authors. Demonstration software is available on request.

REFERENCES

1. Arnott, A. L., & Javed, M. Y. (1992). Probabilistic Character Disambiguation for Reduced Keyboards Using Small Text Samples. *Augmentative and Alternative Communication*, 8, 215-223.
2. Minneman, S. L. (1985). A simplified touch-tone telecommunications aid for deaf and hearing impaired individuals. *Proceedings of the 8th Annual Conference on Rehabilitation Technology (RESNA '85)*, pp. 209-211. Memphis, TN: RESNA.

Martin King
Vashon-Able
P.O. Box 2300
Vashon, WA 98070
(206) 463-6898
MTK@HALCYON.COM
CompuServe (75262, 1563)

SINGING ON THE MULTIVOICE

Mark I. Bresler MBME
Southwest Assistive Technology Inc.
Oklahoma City, OK

ABSTRACT

Programming songs for the MultiVoice speech synthesizer involves creation of files specifying pitch and duration of each phoneme.

This paper illustrates a technique for the MultiVoice to assist in this process by performing the text to phoneme translation.

BACKGROUND

Many individuals who use a voice output communication aid (VOCA) desire the ability to have songs sung by the (VOCA). This is a time consuming, multi-step process. First, text or phonemes must be typed into the VOCA or a word processing file and the note and duration of each word or phoneme must be specified. If phonemes are to be used, the song text must be translated into phonemes. This paper illustrates a method allowing the MultiVoice to perform text to phonemes translation. Any computer with word processing and communications programs incorporating the necessary features can be used. The author used a Macintosh PowerBook 145B with Claris Works 2.0 for word processing and Red Ryder 10.3 for communication between the computer and MultiVoice. The Claris Works serial communication section was repeatedly tried, but would drop characters during transmission.

IMPLEMENTATION

Song creation involves the following steps:
(1) Type song text into a word processor, with a period at the end of each line.

Original text fragment (from step 1)
From a distance.
there is harmony.
and it echoes thru the land.

(2) Connect the computer to the MultiVoice.
The communications program must be set to the same baud rate as the MultiVoice, have a 5-second pause between sending each line, have screen capture on, and enable local echo. The connection can be checked by typing words in the communication program and making sure the text is spoken by the MultiVoice.

(3) Set the MultiVoice to return phonemes from text by sending the MultiVoice the following: ESC P0;81;256;0z ESC\
The characters are Escape, uppercase P, zero, semicolon, 81, semicolon, 256, semicolon, zero, semicolon, lowercase z, Escape, backslash

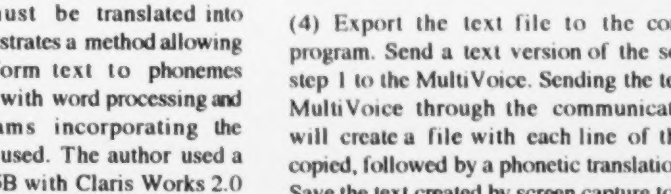
Please note: the MultiVoice will continue to translate phonemes until it is turned off.

(4) Export the text file to the communication program. Send a text version of the song typed in step 1 to the MultiVoice. Sending the text file to the MultiVoice through the communication program will create a file with each line of the input file copied, followed by a phonetic translation of the line. Save the text created by screen capture to disk.

Text fragment with phonemes (from step 4)
From a distance.
fraxm ax d'ihstixns.
there is harmony.
dhehr)ihz hx'aarmaxniy.
and it echoes thru the land.
ehnd `iht 'ehkowz thr'uw dhax l'aend.

(5) Export the text file again, but this time turn local echo off, save the screen capture to disk. This will create a file of just the phonetic translation.

(6) Print the file created in step 4. This will serve as a reference printout.


From A Dis-tance there is har-mo-ny and it ech - oes thru the land
From A Dis-tance there is har-mo-ny and it ech-oes thru the land
From A Dis-tance there is har-mo-ny and it ech - oes thru the land
From A Dis-tance there is har-mo-ny and it ech - oes thru the land

Fragment of the musical score showing four part harmony (lead voice used in examples)

BEST COPY AVAILABLE

Text fragment, phonemes only (from step 6)
fraxm ax d'ihstixns.
dhehr)ihz hx'aarmaxniy.
ehnd `iht 'ehkowz thr'uw dhax l'aend.

(7) Determine how fast a song is to be sung. For this example, it was desired to match the pace the Sweet Adelines of Oklahoma City, sung "From a Distance". By listening to a taped performance, and reading the sheet music it was determined that 70 measures were sung in three minutes and 42 seconds, or 222 seconds. Dividing 222 seconds by 70 measures equals 3.17 seconds per measure. This was rounded up to 3.2 seconds per measure or whole note. From this, a half note lasts 1.6 seconds, a quarter note .8 seconds, a 32nd note lasts .1 seconds, etcetera.

(8) Using the file created in step 5, add an open square bracket, [, as the first character and a] as the last character.

(9) Replace all periods with a space. A search and replace function of a word processing program can be used.

(10) Using the alphabetized phoneme table below, insert <,> after the first phoneme. This will allow the phoneme to be sung at a specified note for a specified duration.

(11) The MultiVoice can sing over four octaves. The lower three octaves can be specified by numbers 1 to 37, while notes for the top octave are selected by frequency. Using 1 for the "C" two octaves below middle C, and 37 for the "C" an octave above middle "C" [1], [2], insert a number between the comma and right angle bracket. If phoneme duration is to be changed from the default, it can be specified in milliseconds by the number after <. For example, to say "aa" at middle C for one-tenth of a second, use the following: aa<100,25>

(12) Move the cursor immediately after the next phoneme to be altered in pitch or duration and insert <,>

(13) Repeat Steps 11 and 12 until the end of the song is reached.

Refinements

Judy Hensman-King provides the following song programming advice:

"Notes are sung by lengthening the vowel sound in words and not the consonants. Therefore each word needs to be split into syllables of initial consonant and vowel, and final consonant. Consonants on the end of words can be given an automatic time value of 50 milliseconds. Repeated notes do not require a note value - only a time value." [3] If the note has not changed from the proceeding phoneme, there is no need to insert a number.

Diphthongs

Diphthongs are phonemes composed of two sounds in sequence. These create problems when sung over two or more notes because the end sound is repeated. The person translating the song might need to change all but the last phoneme to a phoneme of the first diphthong sound. For example "no" translates to now, of "n" and "ow". Sung over four notes in "From a Distance" this becomes:
now<600,27>ow600,25>ow<200,24>ow<200,22>
for a smoother sound this was changed to:
nuh<600,>uh<600,25>uh<200,24>ow<200,22>

Data pacing

This next step was required when using the Red Ryder program to "proof listen " to the song as it was being translated and refined. It may not be needed for the song file when used with VOCA software.

The next task is to pace the transmission of the serial data from the computer to the MultiVoice. Computers can send information to the MultiVoice faster than it speak. Again, using "From a Distance" as an example, a file of 5,866 bytes takes 260 seconds to sing for an average data rate of 22.6 bytes per second or a baud rate of 226. Because the input

Text fragment specifying duration and pitch (after step 13)
[f<100,>r<100,>axm<400,34> ax<400,36> dih<400,>st<,29>ix<1200,>ns
dh<200,36>eh<400,34>r)ih<200,32>z
hx<,36>aa<400,>rm<,34>ax<200,>n<,32>iy<800,>iy<800,35>iy<800,36>
eh<400,>nd `ih<400,34>t<,32> eh<400,>k<,25>ow<800,>z th<,27>ruw<800,> dh<,32>ax<800>
lae<800,>ae<200,31>ae<200,29>ae<1600,27>nd].

buffer of the MultiVoice is smaller than needed to hold the entire song, some data pacing is required. Initially a baud rate of 9600 and XON/XOFF [4] handshaking was tried, but without success, and characters got lost or garbled. Lowering the baud rate to 1200 did not solve the problem, nor did spacing each character by 3/60 of a second. Success was achieved by breaking the song into several sentences, starting each with a left square bracket, and finishing each with a right square bracket and a period. The communication program was set to wait 9 seconds between lines. Each sentence was followed by one or two carriage returns as needed. This was determined by experimentation, sending the song to the Multivoice, observing if the text being downloaded was getting too far ahead of what was being spoken, and adding carriage returns as needed to prevent the input buffer from completely filling up. Care was also taken not to add more returns than needed as the MultiVoice would then finish what is stored in it's buffer before a new sentence is completely sent.

Once the song is translated, it needs to be copied for each VOCA.
For use with Words+ Talking Screen software, the title should be less than eight characters, a period, and "SNG". The file must be saved as a text file.
For Prentke-Romich products with MultiVoice, there are less restrictions on names, but the file must be saved as a text file.

Alphabetized phoneme table [5,6,7]

aa ae ah ao ar aw# ax axm ay# b* ch d* dh e eh el en er ey# f g* hx ih ir ix iy jh k* l m n nx or ow# oy# p* r rr s sh t* th uh ur uw v w yu yx z zh

The accent marks, parentheses and other punctuation are stress and syntactic symbols generated by the MultiVoice when translating text to phonemes. When pitch and duration are not otherwise specified, these symbols modify the pitch and duration of text spoken by the MultiVoice.

CONCLUSION

This paper discribes a method to utilize the MultiVoice speech communicator to translate song text to phonemes as a step to translating songs to be sung by the Multivoice.

ACKNOWLEDGEMENTS

From a Distance was written by Julie Gold, BMI music.

The author would like to thank Elizabeth Allen, NORCE music therapist for giving a crash course on reading music, Jim Massey, Director of the Oklahoma City Chorus of Sweet Adelines Inc., Trudy Posner, my wife, and Sweet Adelines tape evaluator, Shirley Fine Sweet Adelines music librarian, and Beulah Bresler, my mother for her proofreading advice.

Mark I. Bresler, MBME
Southwest Assistive Technology Inc.
PO Box 60603
Oklahoma City, OK 73146

REFERENCES

1) MultiVoice manual Table 5-4
2) Frequencies for the top octave are: C# 554.5 Hz, D 587.6 Hz, D# 622.4 Hz, E 659.6 Hz, F 697.8 Hz, F# 740.2 Hz, G 784.4 Hz, G# 831.0 Hz, A 880.0 Hz, A# 932.4 Hz, B 988.0 Hz, C 1046.8 Hz. The top octave is quite high for the Multivoice, you may want to transpose the notes down an octave.
3) Programming a song, included in "Next Steps With Liberator Notebooks and Related Macros" Janet S. Lehr, M,.S. CCC-SLP April 30, 93.
4) XON/XOFF is a "handshaking" protocol where a unit sends serial data to another unit until the receiving unit fills its input buffer to a certain point at which time it sends a XOFF stop transmitting code back to the transmitting unit. Once the receiving unit has emptied its buffer enough, it sends a XON command to the transmitting unit to resume transmission. This process continues until the complete file is sent.
5) Adapted from MultiVoice manual Table D-1 (please note phoneme " ch " is not listed, but generated by the MultiVoice in phoneme logging mode.)
6) Asterisk indicate phonemes for which duration cannot be altered. MultiVoice manual page 72.
7) Pound sign indicates vowel dipthong

A COMPARISON OF THE INTRODUCTION OF VOICE-OUTPUT AAC DEVICES WITH TWO SCHOOL-AGE CHILDREN WITH ATHETOID CEREBRAL PALSY

Joyce Hignett, MS(c), S-LP
Lethbridge Health Unit
LETHBRIDGE, ALBERTA CANADA

ABSTRACT:

One of the main difficulties facing educators, family members and therapists working with nonverbal children with athetoid cerebral palsy (CP) is finding effective methods of introducing augmentative and alternative communication (AAC) systems. Examples include adapting games for AAC use, facilitating participation in class discussions and peer interactions, incorporating the AAC system into phonics, math or essay assignments. Introducing a voice-output AAC system involves consideration of the child's motor skills, nonverbal communicative competence, emotional readiness, interests and needs, and the agenda of parents, teachers, and therapists. A comparison of this introductory process with two children with athetoid CP is described.

BACKGROUND:

An estimated 2.0 per every 1000 Canadians are affected by CP, approximately 11.7% of those with athetosis. Athetoid CP impairs control of muscle tone and movement throughout the body and face, and ranges from mild to severe. In its severe forms individuals cannot speak and require wheelchairs and other equipment. Cognition is sometimes affected. Limitations in the ability to interact with people and the environment make education, peer relationships and daily living skills looming challenges.

Due to advancing technology, sophisticated voice-output AAC devices help nonverbal people communicate. However, even when specialized assessments are conducted and AAC devices are purchased, introducing the device into daily use is a complicated process.

Part of the difficulty with the introduction of AAC devices is that they require competence in many skills. The motoric demands (either scanning or direct access, via the individual's most controlled muscle group) are easier to master when practised with limited programmed options (ie: 4 messages vs 32) and in a non-distracting environment (ie: one-on-one vs large groups). In addition, the user must understand the symbol system and know when to use the device. Comparable to learning how to use a computer, AAC devices are not always efficient initially; they often seem foreign and thus are not motivating. When the users are children, their tolerance for new and frustrating activities can be low.

In contrast to the time and effort needed to master AAC devices is the long-term goal of their use: to be an effective, efficient and motivating mode for communicating unlimited types of messages in unlimited settings.

OBJECTIVE:

To assist children with athetoid CP and their families and teachers, transdisciplinary intervention and specialized assessments are followed by analysis of the child's environment and areas of strength and need to establish successful initial AAC device use.

APPROACH:

The clients, aged 6 and 10 years, begin family-centered intervention via transdisciplinary (Physiotherapy, Occupational Therapy, Speech/Language Pathology, and Social Work) assessments, followed by specialized AAC assessments to determine the best site for switch access and appropriate AAC devices. Prerequisite skills for voice-output use (communication using Yes/No responses, choice-making with objects or symbols, introduction to voice output with loop tapes, switch use with toys, tape recorders, appliances, computer programs) are addressed to establish active communication and complete switch control before the AAC device is purchased.

When the clients' AAC devices are purchased, the intervention programs incorporate their use, based on the following factors:

a) success with prerequisite skills;
b) emotional readiness for and acceptance of

the AAC device;

c) client's ability to communicate with other methods, and areas of greatest communicative need/desire;
d) family, therapist and educator agendas for AAC use for communication, language development and academic purposes;
e) cognition, vision, hearing, motor abilities and related medical factors;
f) environments or activities that facilitate AAC device use throughout the client's day;

RESULTS:

CASE #1: Profile:

A., a 6 year-old male, participated in a grade one program with aide assistance. His nonverbal communication included vocalizing "uh" for "yes", shaking his head for "no", selecting picture communication symbols (PCS) from an eye gaze board, and selecting objects by eye gaze. A. used his right temple to access a single switch for cause-effect and step/direct scanning activities. A Scanning Macaw (Zygo) was purchased for his educational and early communicative needs.

A.'s Vision, hearing and cognition were believed to be unimpaired, although no recent standardized testing had been completed. Educators and family wanted to capitalize on A.'s academic success to motivate use of his Macaw. A.'s switch use was nearly 100% accurate when measured in non-distracting situations, with activities he enjoyed, people he knew, and no more than 2-3 options to scan. He practised switch use almost daily at home, weekly at transdisciplinary therapy sessions, and occasionally at school. A.'s "yes/no" responses were easily interpreted, and his eye gaze choosing for objects and activities was rapid, with up to 4 PCS presented. In addition, his classmates interacted with him without adult prompting.

A. was emotionally ready for a sophisticated AAC system to assist socially and academically but did not view his Macaw as part of his identity. Because of his efficient "yes/no" and eye gaze skills, A. was frustrated with the time and effort needed to use the Macaw. His communicative role had been as a receiver of information, a responder to questions, and a chooser of concrete objects and activities.

He needed practice with other pragmatic aspects of language, such as initiating, asking, clarifying, explaining, interrupting, and describing. Finding environments to facilitate the use of AAC devices was difficult. At home, games were adapted for his input, but the fast pace of the classroom was not conducive to early Macaw use. Much classroom work was completed individually, and discussions were difficult to predict in advance.

PLAN:

A. needed to view his Macaw as a useful, motivating part of his life. His confidence with early literacy skills was a route to gain success with the device and satisfy educator goals.

1. A. would help select the "voice model" and the messages to be recorded.
2. At home, the Macaw would be programmed with 2-3 messages for games, to be altered as often as A. desired.
3. At school, the Macaw would be introduced gradually. Initially, A. would practice with his assistant in activities with clear expectations (eg: simple phonics or math). Once comfortable, A. would work with a peer or small group. Social messages (eg: "I don't know", "I hit the wrong key"; "That was great") would be taught in role-playing activities and transferred to group use once A. demonstrated competence.
4. A word processing program would be introduced to encourage written communication.
5. Consultation with the Speech/Language Pathologist would be ongoing, and A.'s progress would be re-evaluated after 3 months.

CASE #2: Profile:

T., a 10 year-old girl, was beginning integration in a grade 4 classroom after inclusion in a segregated special education room with numerous assistants. Her nonverbal communication included looking up for "yes" and down for "no", selecting pictures or PCS from an eye gaze board and real objects by eye gaze. T. used her left temple to access a single switch for cause-effect and simple step scanning activities. A scanning Macaw was purchased for her needs.

T.'s vision and hearing were considered within normal limits. A recent cognitive assessment estimated her abilities at a "concrete level", roughly equivalent to a child entering kindergarten. She enjoyed social interaction and was familiar with her head switch. T.'s "yes/no" and eye gaze choices were easily read when she was sure of her responses. Her family and educators were motivated to help T. communicate.

T.'s switch use was inconsistent due to the influence of extensor tone, asymmetric tonic neck reflex, excitement, fatigue, poor attention to and comprehension of some tasks, and varying assistant AAC training skills. Her understanding of the Macaw's voice and identification with the device was questionable. T. was often communicatively passive and appeared to be losing basic concept knowledge, possibly due to her long-term limited ability to communicate. Similar to A., T.'s required structured practice with many communicative functions. Expectations for T., both academically and communicatively, needed to be established.

PLAN:

All parties agreed to proceed with use of the Macaw in spite of T.'s inconsistent prerequisite switch skills.

1) Because T.'s educational program was in transition, initial use would occur at home. Storytime was chosen for an introductory activity, because it was non-stressful, had few cognitive demands, and enabled comments with no right or wrong answer. Two messages were programmed, to be used daily until T. demonstrated control at home, and later at school during one-on-one reading periods.
2) Prerequisite communication skills would continue to be addressed at home, school, and therapy sessions.
3) A physiotherapy program to address neck and shoulder girdle stability for improved switch control would be implemented.
4) Consultation with the Speech/Language Pathologist would be ongoing and T.'s progress would be re-evaluated monthly.

DISCUSSION:

Comparison of the two clients described in this study reveals key principles in the introduction of voice-output AAC devices. These principles are the complexity and time commitment of the skills needed and the advantages of a structured team approach.

Language acquisition is a complex process which occurs over many years. Children without disabilities naturally explore their environment, and as a result acquire skills in interacting, conceptual knowledge, and problem-solving. By school age, most children can ask and answer questions, request, protest, describe, convince, clarify and interrupt, and numerous other skills. Nonverbal children with athetoid CP, even with intact cognition and dedicated families, are unable to experience the world in the same way as nondisabled children. In many cases, they enter school with deficient problem-solving and interaction skills. Accommodating for deficiencies is a long-term challenge, one which can be facilitated by the use of a voice-output AAC device.

As with many areas of technology, AAC devices are only as effective as the individuals designing their use. Consultation from a specialized transdisciplinary team is an optimal way to introduce their use. Each member of the team contributes his/her expertise (language, equipment, motor skills, family support) to maintain objective and varied goals, as well as supporting other members' goals for consistent intervention. The team's role in educating family members and school personnel is as important as therapy with the child. Because use of AAC devices is a life-time process requiring ongoing modifications, significant others must learn how to operate the device, when to change programmed messages, and the types of messages to include. In essence, the team assists teachers and parents to become the experts in facilitating the child's AAC use.

The investment of time and specialized skills adds to the satisfaction from helping a child with athetoid CP communicate via voice-output AAC devices. It can open the doors to an enhanced quality of life, not only for the child, but for his/her family and all who want to interact with him/her.

REFERENCES:

McDonald, E. (ed.) Treating Cerebral Palsy: For Clinicians by Clinicians
Pro-ed, (1987) Austin, Texas 78758

The Cerebral Palsy Association in Alberta - Brochure

ACKNOWLEDGEMENTS:

Permission for this paper was provided by the Speech Department and Administration of the Lethbridge Health Unit.

Thank-you to the clients and their families for their valuable information.

Joyce Hignett, MS(c), S-LP
Box 2291 LETHBRIDGE, ALBERTA T1J 4K8
CANADA

MULTIMODAL COMMUNICATION SYSTEMS: ENHANCING INTERACTION SKILLS FOR AAC USERS

Jacqueline Dupuis, M.Sc., S-LP(C) and Beth Thompson, M.Sc., S-LP(C)
Sunny Hill Health Centre for Children
Vancouver, B.C., Canada

ABSTRACT

Many nonspeaking people now have the opportunity to use technical and non technical augmentative and alternative communication (AAC) systems. An important key to their communicative efficiency with these systems is to combine them so they work together to create an efficient communication 'package.' Although it is assumed that effective communicators will use a combination of communication systems and strategies, we have found that many communication programs focus on only one mode. We also note that when multiple systems are being used, they are not designed to complement each other and are therefore difficult to support. Multimodal communication systems are defined as the planned integration of multiple communication strategies both technical and nontechnical. This discussion will outline the benefits of supporting multimodal communication systems, descriptions of optimum programming, and guidelines for their development. Strategies for implementation, communication training and program maintenance will be highlighted.

BACKGROUND

As therapists on assistive technology teams, we are charged with the responsibility of assessing, planning, and programming for children with complex motor disabilities. These individuals often require specialized seating, mounting, and access, in addition to AAC systems. Typically, AAC Users attend a number of educational and community settings throughout their regular schedule, and ideally want to have systems that are portable and easy to manage. Many Users cannot access all of their vocabulary and message needs through one communication system, and require support to combine or integrate their communication systems so they can be more efficient and successful in social interaction (4).

Effective use of a technical communication system requires an appropriate non technical system, which can be used in conjunction with, or instead of, the technical system. Non technical systems can be integrated so that they can carry the weight of the communicative intention, and establish the flow in a social interaction (2). For example, an AAC User can initiate a turn by vocalizing and eyepointing to a conversational partner (2), can use a voice output communication aid (VOCA) to ask "May I speak to you," and can use symbol board to indicate a topic or situation choice.

Research has demonstrated that an AAC User's communication interaction is adversely affected by a slow rate, and a reduced number of conversational exchanges (3). Community or unfamiliar partners are more likely to participate with an AAC User if he/she uses typical nonverbal communication signals such as vocalizing, head position changes, and facial expressions.

Team and family reports indicate that a VOCA's history with an AAC User is variable (8), and may change according to programs or focus of goals for a child. Devices often become secondary if priorities change, and nearly 1/3 of all purchased VOCA's may be abandoned (1).

Our task, as consultants to family and school teams, is to develop the individual's communication abilities to their maximum potential. Our role includes development and use of non technical AAC systems that can grow with the User, the development of technology skills for communication devices, and strategies for use of the systems in all environments (9).

STATEMENT OF PROBLEM

AAC Users may require multiple communication systems to support their conversational interactions, particularly with unfamiliar communication partners. Systems need to be transparent in the greater community and easy to interpret for all potential listeners.

The AAC User's competence is often judged by their ability to initiate conversation, state topics, maintain an efficient pace, and share novel information (7). Their systems need to be dynamic and structured for interactions.

Conversational breakdowns occur when the non technical and technical AAC systems do not support each other, and the AAC User cannot use them interchangeably. "An individual with an electronic aid will always need a nonelectric aid, not just as a backup but for those situations in which the nonelectric aid is more effective. Each aid is on a continuum with the others, and they are complementary to each other." (5)

APPROACH

The development of the integrated communication programs that we prescribe, begin with an assessment of the communication environments, communication observations, establishing priorities, and communication training. The future AAC User is observed in as many environments as possible. The primary and secondary caregivers are interviewed, and their impressions of communication style are shared and used in the planning.

The User's communication strengths are incorporated into the system, and the family and team are encouraged to see the AAC system as an enhancement and not a replacement for "natural communication" (6). Sample situations are identified and communication systems and goals are planned so that teams can see the advantages of integrating systems. Caregivers and partners are responsible for learning facilitative techniques to keep interactions going, and to meet the conversational goals of the User.

IMPLICATIONS

Successful communication programming requires the involvement and ongoing support of many people. Developing AAC systems can be labour intensive. Integrated communication systems may appear to increase the workload, however the outcome of a competent communicator is worth the effort.

Factors to consider when developing, training and maintaining integrated systems will be highlighted. Illustrations regarding what works and what does not, will be provided.

DISCUSSION

The ultimate goal for our clients, is that they will become functional and contributing members of their communities, educational settings, and future work settings. Their success depends on their ability to favourably compete with typical communicators, and therefore they must have AAC systems that will support their transitions, and be appropriate for many situations. By integrating nontechnical and technical communication systems, the focus is on efficient interactions, supporting natural communication signals, and using the fastest interchange possible.

In our clinical experience, we have found that nonspeaking individuals who have been encouraged to use multiple communication systems and strategies, have success in a greater number of communication environments, have a broader range of communication partners, and are more likely to maintain conversational interchanges. A basic level of mastery with 2 or more communication methods or systems significantly enhances the individual's ability to be successful in all areas.

REFERENCES

1. Blackstone, S. (1992). Abandonment of Assistive technology: What consumers know and professionals need to find out. Augmentative Communication News, 5:3, 1-3.

2. Blackstone, S. (1991). Intervention with the partner's of AAC consumers: Part 1: Interaction. Augmentative Communication News, 4:2, 1-6.

3. Blackstone, S. (1990). The role of rate in communication. Augmentative Communication News, 3:5, 1-8.

4. Blackstone, S. (1993). Thinking a little harder about communication displays. Augmentative Communication News, 6:2, 1-7.

5. Fishman, I. (1987). Electronic Communication Aids. Selection and Use. A College-Hill Publication.

6. Goossens', C., Sapp Crain, S., Elder, P. (1992). Engineering the Preschool Environment for Interactive, Symbolic Communication. Southeast Augmentative Communication Conference Publications.

7. Light, J. (1989) Toward a definition of communicative competience for individuals using augmentative and alternative communication systems. Augmentative and Alternative Communication. (AAC). 5:137-144.

8. Smith-Lewis, M. (1994). Discontinuity in the Development of Aided Augmentative and Alternative Communication Systems. AAC, 10:1, 14-26.

9. Thompson, B., Dupuis, J. (1993). Making It work: Strategies for Including Aug. Comm. in the Classroom. Presented at the Canadian Speech-Language Pathology and Audiology Conference, May 1993.

Jacqueline Dupuis
Communication Development Department
Sunny Hill Health Centre for Children
3644 Slocan Street
Vancouver, B.C
Canada, V5M 3E8
ph. (604) 436-6514
fax. (604) 436-1743
Internet. jackied@sunny.wimsey.com

A HEADCONTROLLED DYNAMIC DISPLAY AAC SYSTEM

Albert M. Cook, Susan M. Hussey and Mary Currier
Assistive Technologies 2000, Sacramento, CA; University of Alberta, Edmonton; California State University, Sacramento and Placer Infant Development Program, Roseville, CA

Abstract

A mouse emulating interface and dynamic display software were used to allow a teenage AAC user to move from manual head-based light pointing to an electronic voice output communication aid. Her success with this system during a five month trial led to the purchase of the system. The training process by which she developed competence included the use of a drawing program as well as the dynamic display software.

Background

Janice is a 16 year old girl who suffered a traumatic brain injury at age 3. She has very limited hand/arm use and fair to good head control. She is responsive to family members, and her major communication need has been social closeness. At the beginning of this study, communication goals were to increase classroom participation and expand communication beyond social closeness.

Over the past several years we have worked with Janice to increase her ability to exercise control over her environment through manipulation of objects and through communication. This began with the use of a single switch and progressed to a head-mounted light. Initially, she used real objects (e.g., a piece of a jig-saw puzzle or a bottle of nail polish), We then used enlarged line drawings. The activities then became initial choices that lead to more choices. Janice was also introduced to more abstract language concepts (e.g., "more" and "stop"). She also demonstrated greater independence and reduced passivity.

Objective

Although the light pointer was successful in meeting several of Janice's objectives, it was evident that an electronic AAC system was important to the achievement of her communication goals. The most important characteristics for this system were: (1) voice output, (2) a vocabulary organization which paralleled her sequential use of multiple pages with the light pointer, and (3) access by head controlled pointing. Thus, the objective of this study was to determine the feasibility of Janice using a head controlled pointer with a dynamic display voice output communication device.

Method/Approach

None of the manufacturers of the dynamic display devices had head pointing systems available. However, the Talking Screen software (Words+) was available in an MSDOS version. We then explored the possibility of using the Headmaster (Prentke Romich) with the Talking Screen software to provide the desired set of device characteristics. Both companies assured us that their products would "work with any DOS-based software (or mouse)".

To evaluate the system, both the Talking Screen and the Headmaster were leased and installed on the family's computer. A five month training program was devised to: (1) develop Janice's skill in using the Headmaster, (2) transfer her communication skills from the light pointer manual system to the electronic device and (3) evaluate the feasibility of the electronic system for Janice. In the later category there were concerns regarding some visual limitations and their effect on seeing the computer-based pictures, and how much the voice synthesis output would contribute to Janice's use of the system.

In order to introduce the Headmaster and develop Janice's skill in using it, a mouse controlled drawing program (KidPix) was used. This helped Janice develop basic control over the on-screen cursor and to develop an understanding that this cursor functioned in a manner similar to her light pointer, i.e., as an indicator of her choice. This understanding of cursor movement took place over a period of a few sessions, and Janice began using the Talking Screen software and Headmaster for communication as she had previously used her light pointer.

Throughout the communication training, a "prompt-free" (1) approach was used. Janice was shown line drawings representing an object, activity or emotion. When she selected this item, the trainer responded to the selected item. In this way Janice learned the meaning of the symbols. Initially, the same symbols used with the head light were used on the computer screen. This was possible because PCS symbols (Mayer-Johnson) were used with both the light pointer and the Talking Screen software.

Results

As is often the case when using products from different manufacturers, there were incompatibilities between the Talking Screen software and the Headmaster. After trying several software drivers (each of which worked with Talking screen and a Microsoft mouse but not with Headmaster), it was determined that a Microosft driver was required by Headmaster. This driver also worked with the Talking Screen. Unfortunately, this period of trial and error was very frustrating to Janice and to her family.

During the first two and a half months of the study, the majority of the time was spent in solving the hardware/software problems, getting Janice used to the screen cursor movement, and developing an initial set of choices based on those previously used with her light pointer. Initially, one symbol was used in the center of the screen to encourage Janice to remain in midline position. During this period Janice began to use the unique capabilities of this system through such activities as calling her mother into the room or teasing her brother and sister using the voice synthesizer. She averaged 9.5 independent choices per session using the Headmaster and Talking Screen during this period.

During the last two and one-half months of the training program, Janice continued to use the system with a greater number of symbols on each page and sequences of three or more pages. During this period Janice made approximately 13 selections/session. Of these selections about 70% were considered to have been "intentional" based on Janice's reaction, the conversational situation and other similar secondary cues. The remaining

30% were generally caused by Janice's inexperience with the system. For example, if she relaxed her head (rather than keeping it up and in midline position), the cursor moved to the upper left corner of the display. The Talking Screen software was written such that repeated selections are generated if the cursor is kept in one location. Over the 2 1/2 month training period Janice developed greater head control and was able to keep her head upright. Both the quantity and quality of choices increased over the training period. The quality was judged by the effectiveness of the communication (e.g., did she make selections which obtained clear results for her?) and by its appropriateness (e.g., did the selections conform to the context of on-going conversations). One of the most significant changes noted during this period was a gradual increase in Janice's assertiveness.

Discussion

Based on the success of the five month lease and training program, Janice is purchasing the system together with a laptop computer for portable use. This will increase the system functionality by allowing her to use it in school and during frequent family outings in the community. Janice previously used her head light at school, but it was difficult because of its dependence on a partner (e.g., to switch pages as topics were selected) and its lack of voice output.

Since Janice has very little controlled use of her arm and hand and also had great difficulty with scanning due to the necessity to react quickly to choices, it was critical to provide a direct selection system for her. Also, since her vision is limited it was necessary to use relatively large symbols. Without a dynamic display-type of system, it would have been very difficult to generate a sufficiently large vocabulary for Janice's use.

Despite her very significant physical and sensory limitations, Janice has demonstrated a keen sense of humour, an understanding of language concepts such as categorization and sequencing and the ability to appropriately use communication strategies. None of this would have been as evident had it not been for the ability of the technology to combine her use of head movement for direct selection, dynamic display software, and voice synthesis output.

References

1. Mirenda P and Santogrossi J: A prompt free strategy to teach pictorial communication system use. AAC 5: 1-13, 1985.

Acknowledgement

We are indebted to the Words+ and Prentke Romich Companies for their cooperation and support of this project. The success obtained would not have occurred without the dedication and support of the consumer and her parents.

Albert M. Cook
Faculty of Rehabilitation Medicine
University of Alberta
Edmonton, AB T6G 2G4
CANADA
voice: (403) 492-5991
fax: (403)492-1626
e-mail:
ACOOK@CORB.REHAB.UALBERTA.CA

EVALUATING THE USE OF TALKSBAC WITH NON-FLUENT DYSPHASIC ADULTS

Annalu Waller[1], Fiona Dennis[1,2], David M. Millar[1], Alistair Y. Cairns[1],
Jan K. Brodie[2], Alan F. Newell[1], Ketron Morrison[2].
[1]MicroCentre, University of Dundee; [2]Dundee Speech & Language Therapy Service

Abstract

A research project at the University of Dundee's MicroCentre has developed a predictive communication system called TalksBac, the details of which were described at the RESNA conference in 1994 [1]. The purpose of this paper is to report on the application of TalksBac with four non-fluent dysphasic adults.

Background

The two year TalksBac (Talking and Learning Knowledge System for Better Aphasic Communication) project was established to develop and evaluate the use of a predictive communication system designed to meet the needs of a group of non-fluent dysphasic adults. The first year of this project focused on software development while the second concentrated on the user involvement.

TalksBac consists of two stand-alone software programs which run on a Macintosh platform. The "user interface" allows the user to retrieve prestored conversational sentences by choosing who they are talking to and what they are talking about from a list of names and one of topics. A list of a maximum of four probable sentences and story titles is then displayed on the screen. All selections are made by clicking on the target using a trackball. Selecting a sentence results in synthesised speech output. The second program, the "carer interface", is used to enter information via the keyboard.

The software uses the "person" and "topic" parameters, in conjunction with frequency and recency factors, to identity the most probable conversational items which are displayed to the user. The dynamic nature of the retrieval process allows the system to adapt to the user's conversational patterns and eliminates the need to memorise codes - retrieval depends on the user's ability to recognise familiar words and phrases. The emphasis on recognition, rather than message production, is of benefit to augmentative communicators with language dysfunction in that they do not have to identify the specific target item before retrieval.

User Involvement

Four non-fluent dysphasic clients (three men and one woman), all at least one year post onset of their dysphasia, were assessed and selected for participation in the project. Their comprehension is better than their expression and they are able to follow everyday conversation, simple commands and can consistently answer yes/no questions. The primary carers (the spouse in each case) were very interested in the project and agreed to support the user.

Each volunteer received a Macintosh PowerBook Duo with the TalksBac system installed and a TalksBac manual. The speech and language therapist visited each volunteer and their spouses to train them to use the system. The spouses were encouraged to enter conversational information into the system between visits and the speech and language therapist concentrated on ensuring that the users could retrieve this information.

The users and their carers contributed ideas to the design and functionality of the interfaces throughout the project. The software design process was iterative in that the researchers were able to modify the software in response to observations made while watching the volunteers using the software.

Evaluation Design

The second goal of the project was to evaluate whether or not TalksBac has a significant effect on the functional communication of the dysphasic volunteers. The evaluation looked at two areas of possible change. The first area focused on the volunteers' comprehension and communicative abilities. Although any change in these abilities cannot be solely attributed to the introduction of TalksBac, the information is of value. A battery of formal tests was applied to each volunteer at the beginning and at the end of the project. The battery consisted of the Western Aphasia Battery [2], Edinburgh Functional Communication Profile [3] and Pyramids and Palmtrees [4].

In order to gauge any perceived change in the clients' functional communication, a modified

Communicative Effectiveness Index [5] was administered to the primary carers at the beginning of the project. The carers were asked to mark their response on a linear measure in relation to the client's abilities before onset. The cumulative measurement across all 16 questions was used as a baseline figure and compared to the measurements collected when the test was readministered at the end of the project.

The second area of evaluation was to analyse any difference between unaided (without TalksBac) and aided (using TalksBac) communication. This was achieved by videoing a series of conversations between the volunteers and speaking partners. Each volunteer was asked to interact with a familiar person and a stranger without using TalksBac. This procedure was repeated two months later with TalksBac. Transcriptions of these conversations were analysed using conversational analysis techniques to identify differences in conversational patterns.

Results and Observations

The final results of the conversational analysis and formal testing will be presented. Preliminary results show that the volunteers have great difficulty in initiating and expanding on conversational topics when relying on unaided communication. Using TalksBac provides users with the opportunity to initiate and control conversation to a greater extent. The difference between using TalksBac as an interactional aid (discussing holidays, past experience, etc.) and a transactional aid (needs based) will be discussed.

Several issues were identified during the two year project. The biggest issue being that of information entry [6]. It was planned that the spouses would be responsible for entering information relating to the user's activities or daily needs. Despite group meetings and individual assistance, little information was entered by the spouses (the researchers entered most of the information). One explanation for this observation is that other daily duties are often thought to be more important and it is difficult to see the advantages of using a system when existing communication suffices for most communication situations between the client and the carer. It is difficult to foresee the need of the user to "tell" a friend what happened the day before as it seems irrelevant.

Ongoing Research

The project has been awarded funding for a further two years research. Although there will be continuing software development, the major focus will be on investigating the problem of information entry. Because of the inherent language difficulties associated with dysphasia, the development of a database of conversational material for an augmentative device is difficult, but it may be helpful to train someone other than the spouse to enter information. We also plan to investigate alternative ways to enter conversational information.

Acknowledgements

Joint funding for this two year project has been received from the Leverhulme Trust, the Scottish Home and Health Department, the Esmee Fairbairn Charitable Trust and Hydro Electric

References

[1] Waller A, Millar D, Dennis F, Cairns A. Y, Gregor P, Brodie J. K, Newell, A.F, Morrison K. (1994). TalksBac: A Predictive Adaptive Conversation System for Non-Fluent Dysphasics. *RESNA '94*, Nashville, Tennessee.

[2] Kertesz, A. (1982). *Western Aphasia Battery Test Booklet*. London: Harcourt, Brace, Jovanovich.

[3] Skinner, C., Wirz, S., Thompson, I., Davidson, J. (1984). *Edinburgh Functional Communication Profile: an observation procedure for the evaluation of disordered communication in elderly patients.* Winslow, Buckinghamshire: Winslow Press.

[4] Howard, D., Patterson, K. (1992). *The Pyramids and Palmtrees Test: A test of semantic access from words and pictures.* Thames Valley Test Co.: Bury St Edmunds.

[5] Lomas, J., Pickard, L., Bester, S., Elbard, H., Finlayson, A., Zoghaib, C. (1989).

The Communicative Effectiveness Index: Development & Psychometric Evaluation of a Functional Communication Measure for Adult Aphasia. *Journal of Speech and Hearing Disorders*, 54, 113-124.

[6] Waller, A. (1994). Dysphasia: the Cinderella of the AAC world. Invited paper: *ISAAC Research Symposium*, Maastricht, The Netherlands.

Contact Address

Annalu Waller Ph.D.
MicroCentre
Department of Mathematics and Computer Science
The University
Dundee DD1 4HN
Tel: (01382) 344842
Fax: (01382) 345509
Email: awaller@uk.ac.dund.mic

TEAM PERCEPTIONS OF DYNAVOX™ USERS - SURVEY RESULTS OF FUNCTIONAL NONTECHNICAL AND TECHNICAL COMMUNICATION USE

Beth Thompson, M.Sc., S-LP(C) and Kathie Marina, M.Ed., OT(R)
Sunny Hill Health Centre for Children,
Vancouver, B.C., Canada

ABSTRACT

The Neuromotor Program at Sunny Hill Health Centre for Children provides services to children with disabilities, from birth to 19 years of age, living in the province of British Columbia. Many of the children are served within their local communities, with the Neuromotor Team providing support, education, and training to the community teams. The children's equipment and technology may be prescribed by the Neuromotor Team, in conjunction with the community professionals, and the Program works collaboratively to maintain and update technology and programming needs on an ongoing basis. Surveys were distributed to teams working with children using the Dynavox voice output computer in inclusive school settings. Questions focused on team member characteristics, child communication skills, technical considerations, and team member goals and expectations of communication and social development. This paper will present the results of the initial survey and discuss the plan for ongoing team education and follow-up.

BACKGROUND

Fully inclusive education is the focus of the preschool and school systems in British Columbia. Children with disabilities are integrated into classes with their same-age peers, and 1 to 1 assistance is provided according to the child's needs. Children with motor and communication disabilities often have specialized handling and equipment needs and extensive training of the family and school staff is required to support their needs and their technology in the school and home environments.

Recent literature on training people to implement and use devices has indicated the need for on-going and regular follow-up (3). Training and/or lack of training has been closely associated with frequency of device use (5), and success for independent User use in all environments. It has also supported the need to train partner strategies (4) and to teach partners to recognize the User as an active communicator in a conversational interchange.

"Dynamic displays", which are displays that change when activated by a User, are currently considered to be *state of the art* in technology (2). They can be picture symbol or letter based, and have greater flexibility for the User to page link through a large repertoire of vocabulary to generate original messages and to recall stored messages. The Users have increased access to vocabulary choices, and can change displays without physically changing the overlay, so they can be more independent in device operation. A common example of this technology is the Dynavox, which is a dedicated voice output computer, which can be accessed by direct or indirect selection (7, 8). The Dynavox features both symbols (6) (Dynasyms™) and letter base options (8), and symbols can be modified to include different features including written and spoken messages. Message locations are "page linked" so choices can branch or link to more detailed information or change topics.

RESEARCH QUESTIONS

Five children in our program have been provided with a Dynavox. Team members were invited to attend inservices in their communities regarding the operation of the device prior to its introduction into the classroom. The purpose of this study was to receive feedback from team members of Dynavox Users on the following questions:

1. What are the ongoing educational needs of a team member that contribute to the successful implementation of the device?
2. Are the team members able to identify a change in communicative abilities of the child who uses a Dynavox over a period of time?
3. What are the 3 most important skills the team members want the child to develop by using a Dynavox to communicate?
4. What are the typical technical barriers team members encounter when working with a child who uses the Dynavox?

The information collected is intended to assist our program with monitoring equipment choices, identifying topics for team eduacation, and providing program suggestions that are functional and will facilitate the child's effective interactions in the school, community and home environments.

METHODS

In order to answer these questions a survey was designed focusing on team member characteristics, child communication skills, technical considerations, and team member goals and expectations. Twenty-two questionnaires were distributed by mail to the facilitators with a total of 17 being returned. At the time of the original mail out only four devices had been implemented into the classroom setting. The fifth device will be provided in the near future along with the training workshop for the community team.

Subjects:

Five children from the Sunny Hill Neuromotor Program are currently using the Dynavox in their classroom. They range in age from 4.9 to 6.10 years of age and have used the Dynavox for 0-17 months. Three of the children can directly access the keyboard while the other two use single switch scanning (fig. 1). The literacy level of the children was considered to range from pre-literate to primary level literacy.

Fig.1

CHILD	AGE	DEVICE USE (MONTHS)	GRADE	ACCESS METHOD
1	5.5	17	kinder-garten	scanning
2	6.5	15	1	scanning
3	6.3	15	1	direct selection
4	6.10	8	1	direct selection
5	4.9	0	pre-school	direct selection

The weight (10.5 lbs) and size of the Dynavox (13.2"x10.9"x3") does not easily lend itself to be a portable voice output computer. Therefore the Dynavox is mounted onto a mobility base for ease of portability and access. All five children use a wheelchair as a mobility base and have the Dynavox physically mounted onto their chairs. These mounts have been custom fabricated by the Sunny Hill rehab engineering department. The mounting of the Dynavox needs to be flexible to allow communication partners to quickly and easily reposition the device to adapt to a variety of activities and environments.

RESULTS

The team members who completed the questionnaires included parents, teachers, special education assistants, speech-language pathologists, occupational therapists, and an integration resource teacher. The majority of respondents have had experience with individuals with cerebral palsy and cognitive impairments and have had experience with a variety of non-technical and technical communication systems. Half of the respondents have known the User for more than one year and work with the User for at least one hour per week.

The team members reported that, while the children can access the Dynavox when it is mounted to their wheelchairs, it is often repositioned so that they can use it while seated on the floor and by their desktops.

According to the survey, the children use a combination of non-technical communication systems, with their Dynavox, to express themselves. Vocalizations, picture symbols, gestures and eye pointing are used more often for greetings, to ask for help, to ask to move to another room/activity, to correct a person if they were misunderstood, to make a request, to ask for a new partner, to play a game and to initiate a conversational interaction. The Dynavox is used most often at school and at home and is used to initiate a topic, to play a game and to terminate a topic.

All the team members reported that they received inservicing on the Dynavox and were able to independently charge the battery, make and save an overlay, modify a symbol, page link and use the special functions. Programming was done primarily by the parents and the special education assistants while the vocabulary selection included the User, the teachers and the speech language pathologists. They reported that they often will change the print size and the labels and set up page linking. When a technical difficulty arises the family is the primary contact.

Team members indicated that they would like to have more inservicing on setting up the communication environment and incorporating the Dynavox and other communication systems into the classroom. The barriers to successful implementation that they identified included the speed at which the child can input their selections, the weight of the device and fears that the device will break down. The three most important skills that they would like the children to develop during the school year were literacy, increased participation and communication with peers, and the ability to generate their own ideas.

DISCUSSION

Voice output computers are provided to enable students to communicate and participate more independently in their environments. The success of this equipment is dependent on numerous factors, including customization of the system for the child and the training of the supporting teams. The implementation of the Dynavox into the B.C. school settings has resulted in the involvement of may caregivers. Vocabulary selection and programming responsibilities are being shared between home and school personnel.

It would appear that the inclusion of the Dynavox into the child's life does not prevent the children from continuing to use existing non-technical means to express themselves. Team members expect the children to participate in classroom activities and acknowledge a combination of communication modalities. Community teams are interested in learning more strategies to foster even more participation from the child.

The goals and expectations of the teams have of the non-speaking child using various augmentative and alternative communication techniques were found to be age appropriate for this group of children. The flexibility of the Dynavox to incorporate both symbols and letter base options lends itself to the development of literacy based skills. The page linking capabilities of the device allows the child to access a wide range of vocabulary so that novel ideas can be generated.

All respondents have achieved a basic level of operational competence of the Dynavox by learning about its features and functions and carrying out basic programming operations. The identified need for further inservicing on setting up the communication environment and incorporating the Dynavox and other communication systems into the classroom corresponds with research that outlines that operational competence is a required step towards the development of communicative competence (10).

Ongoing inservicing will be provided to the community team members on an outreach basis, focusing on the content areas identified in the survey. Follow-up surveys will be distributed at the end of the next two school years.

REFERENCES

1. Blackstone, Sarah W. (1990). Assistive Technology in the Classroom: Issues and Guidelines. Augmentative Communication News (ACN). 3:6, 1-4.
2. Blackstone, Sarah W. (1994). Dynamic Displays. ACN. 7:2, 1-3.
3. Blackstone, Sarah W. (1991). For Consumers: Training Issues Part 11: Operational Competence. ACN. 4:3, 1-2.
4. Blackstone, Sarah W. (1991). Intervention with the Partner's of AAC Consumers: Part 1 - Interaction, ACN 4:2, 1-3.
5. Blockberger, S. & Armstrong, R., et al. (1993). Children's Attitudes toward a Nonspeaking Child Using Various Augmentative and Alternative Communication Techniques. Augmentative and Alternative Communication (AAC). 19:4, 243-250.
6. Carlson, Faith. Dynasyms 2000: Manual and User's Handbook, Version 2.0. Sentient Systems Technology, Inc. 1992.
7. Dynavox: Instruction Manual, Version 1.0. Sentient Systems Technology, Inc. 1991.
8. Dynawrite Manual, Version 1.0. Sentient Systems Technology, Inc. 1993.
9. Jinks, A. & Sinteff, B. 1994). Consumer Response to AAC Devices: Acquistion, Training, Use, and Satisfaction. AAC. 10:3, 184-190.
10. Light, J. (1989). Towards a definition of communicative competence for individuals using augmentative and alternative communication systems. (AAC). 5:137-144.
11. Ratcliff, Ann. (1994). Comparison of Relative Demands Implicated in Direct Selection and Scanning: Considerations from Normal Children. AAC. 10:2, 67-74.

Beth Thompson, M.Sc., S-LP(C)
Registered Speech and Language Pathologist
Sunny Hill Health Centre for Children
Neuromotor Program
3644 Slocan Street
Vancouver, BC, Canada V5M 3E8
Telephone: (604) 436-6514
Fax: (604) 436-1743
Email: betht@sunny.wimsey.com

AAC STRATEGIES FOR PROGRESSIVE APHASIA WITHOUT DEMENTIA: CASE STUDY

Cynthia J. Cress, Ph.D., CCC-SLP
Meyer Rehabilitation Institute, Omaha, NE

ABSTRACT

This paper describes multimodality AAC strategies developed for a 60-year-old man with progressive aphasia without dementia. System development began with a communication needs analysis and included communication board, gesture, contextual, and facilitator training intervention. Results of the intervention indicate that the AAC strategies were successfully learned and used with both familiar and unfamiliar listeners, and that the use of visually-based methods was associated with improved length, effectiveness, and complexity of communicative interaction. Suggestions for follow-up are included.

BACKGROUND

Progressive aphasia is a slowly developing language disorder associated with degenerative cortical disease (Bayles, Montgomery, Bryant, & Wood, 1994). Most clients demonstrate increasing problems with auditory comprehension and expressive communication, frequently involving paraphasias, word recall, and naming difficulties (Poeck & Luzzatti, 1988). While cognitive impairments similar to those observed in Alzheimer's disease may be displayed in advanced stages of progression, clients at 6-10 years post-onset may demonstrate nonverbal cognitive skills within normal limits (Northen, Hopcutt & Griffiths, 1990; Sapin, Anderson, & Pulaski, 1989; Weintraub, Rubin, & Mesulam, 1990).

Augmentative communication (AAC) techniques including gesture, speech, communication boards, and devices have been used for persons with aphasia and other acquired disabilities (Beukelman & Yorkston, 1989). The type and extent of use of various techniques often depends on an individual's specific communication needs and the level of conversational participation desired (Beukelman & Garrett, 1988). While AAC has been recommended for persons with other types of progressive disorders, little research has documented specific techniques that are particularly applicable in anticipation of deteriorating language skills (e.g. Bourgeois, 1991, 1992). No documentation is currently available about the relative success of AAC techniques for persons with progressive aphasia without dementia. However, given the relative strengths reported in visual memory, planning, and orientation when dementia is not a component of the language impairment (Northen, Hopcutt & Griffiths, 1990), effective improvement in communication skills would be expected when using a combination of visual and context-based AAC techniques. The following case study describes such an intervention for a man with progressive aphasia without dementia.

CASE DESCRIPTION

CE is a 60-year-old man in good physical health who has been experiencing gradual deterioration of his language skills for the past seven years. He first began noticing occasional difficulties in word retrieval and auditory comprehension in 1987, which was not associated with any head trauma, stroke, or other medical history. By 1990, family members reported that he was having intermittent problems in comprehending spoken and written language, and showed some halting speech and word substitutions. An MRI in 1991 revealed focal atrophy of the left temporal lobe. By Spring of 1992 he was no longer able to teach and retired from his position as a university professor shortly thereafter.

A neuropsychological evaluation in January of 1992 provided a formal diagnosis of progressive aphasia without dementia. Scores were within the normal range on tests of visual processing and learning, arithmetic computation, sensorimotor skills, and complex attention and orientation skills. Particular language difficulties on Boston Diagnostic Aphasia Exam subtests included comprehension of simple commands or complex ideational material, repetition of phrases, phrase reading comprehension, confrontation naming, and verbal associative fluency. A consistent discrepancy occurred on the WAIS-R and Wechsler between low scores on language-related activities such as naming and verbal memory, and normal to high scores on nonverbal problem-solving and abstract integrative reasoning.

By the time of this intervention (1994), CE showed severe auditory and reading comprehension impairments. He did not identify common objects in confrontational naming tasks, even if he could produce those words spontaneously in functional contexts. He did not respond to simple verbal commands unless they were accompanied by repeated gestural and contextual cues. While CE showed occasional sight recognition of words in highly predictable contexts, he was not successful at using written cues to identify concepts out of context. However, visual processing and functional reasoning skills showed no evidence of deterioration. Expression of numbers and dates continued to be accurate, although CE occasionally self-corrected a spoken number or represented dates as serial digits. Language samples taken at the beginning of treatment showed frequent word finding and fluency problems. Familiar listeners report that CE's verbal expression tends to be understandable within context, although CE may produce several sentences before the topic is clear enough to interpret his communication.

BEST COPY AVAILABLE

CE frequently uses gestures, vocalizations, photographs, and location cues to suppliment and substitute for verbal expressions. He accurately locates and refers to detailed information using calendars, clocks, and maps. Family members report that his comprehension is also better with the use of gestures/sounds with verbal messages, although this is not always successful even within familiar contexts. While visual memory is still a relative skill, family members report limited success at using drawings to cue novel or distant topics. CE did use self-generated lists of relative's names/birthdates for occasional conversations with both familiar and unfamiliar listeners, but this has not generalized to broader social situations.

OBJECTIVE

The purposes of AAC with acquired disorders can be comprehensive communication across all topics, listeners and contexts, controlled communication with familiar listeners or contexts, nonconversational activity, and/or augmented communicative input (Beukelman & Garrett, 1988). Based on a need assessment with CE's family, the following objectives were established for his AAC intervention: augmented input, due to his expressed frustration with impaired comprehension, and controlled communication, based on his continued desire to interact with people in familiar contexts. Non-conversational activities were a current area of strength, and communication within these activities tended to be successfully managed by existing techniques. Communication in unfamiliar or group situations has been rejected by CE when available, and he continues to express minimal interest in these situations. Therefore, the AAC intervention addresses: a) cued comprehension and b) augmented expression in routine or familiar contexts, with familiar and unfamiliar listeners.

METHOD/APPROACH

Periodic consultation in AAC techniques had been provided by the author to CE and his family for the past four years. However, given limited face-to-face contact, successful implementation of AAC methods such as picture symbols and strategy modification was sporadic. For the present intervention, CE temporarily relocated to Omaha for a month of intensive AAC development, training, and evaluation. CE received one hour of direct training with AAC techniques 3-4 times/week, and an additional 3-6 hours/week were spent facilitating their use with CE's family. AAC facilitation was also provided in familiar interactive contexts 1-3 times per week.

Two different communication boards were developed for receptive and expressive communication. Figure 1 shows the board developed for receptive communication, which represents the topics and activity management phrases most often introduced by familiar listeners. Items from this communication board were trained and facilitated in CE's home and familiar activities as relevant events occurred. For instance, symbols for "someone's coming"or "I'll be back at", were introduced as listeners visibly gathered materials and prepared to change contexts. Use of this receptive board was also modelled when CE initiated messages that were represented. Since CE's own verbal expression was his best mode for comprehension, this board also introduced cues of "tell me again" and "you tell me" to facilitate comprehension of new information from listeners. During CE's retelling of the message, listeners could then interrupt or modify parts of that message that were incorrectly understood. Facilitator training also concentrated on presenting complex ideas one concept at a time, beginning with references such as day/time, and pausing to confirm CEs comprehension of each concept before adding new information.

Figure 1: Receptive Communication Board

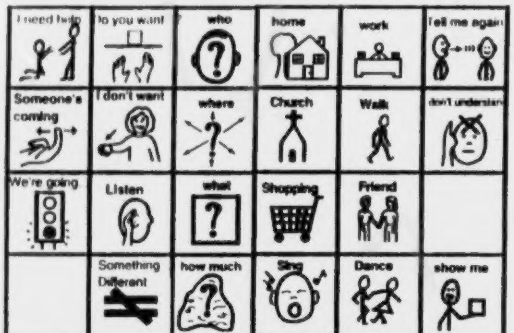
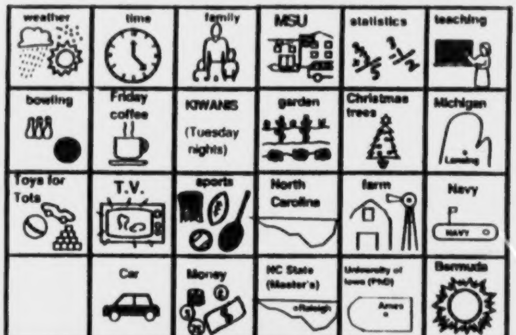


Figure 2: Expressive Communication Board



134

Figure 2 shows the expressive communication board. The left half of the board shows frequently occurring "chat" topics, including preferred activities, events, and people. The right half shows topics of extended narratives that CE frequently initiated with familiar listeners. These symbols were modelled frequently as CE spontaneously produced these topics or narratives. Situational or contextual cues, such as maps and photographs, were presented to elicit conversation on topics that were not spontaneously initiated. These techniques used CE's current verbal strengths to introduce a new graphic symbol mode to support his long-term communication skills.

RESULTS

By the end of the month of intervention, all of the symbols on both boards had been introduced and used in relevant contexts By the third session with modelled use of the boards by a listener, CE began to spontaneously initiate his own messages using the boards. CE demonstrated comprehension of 70% of the symbols on his boards CE was judged to comprehend the symbol if he incorporated the symbol concept into his own communication, confirmed information represented, referred to the symbol himself in appropriate circumstances, or performed tasks or requests related to the symbol. Effective strategies for preparing CE for a message included presenting the board and waiting, mentioning a relevant day or time and prompting CE's repetition of that concept, or signalling CE gesturally to listen. Family members reported that these symbols represented a majority of the routine messages that they considered necessary to convey at this time. Unfamiliar listeners effectively used these strategies only with coaching from familiar listeners. All communication partners observed less success at using the question words for comprehension, since CE has limited strategies for answering such specific questions once he understands them. However, these items were kept on the board to promote CE's ability to initiate those questions, whenever his current verbal strategies become ineffective. Also, the cues for "tell me again" and "you tell me" were rarely effective. CE did often expand his communication modes (e.g. adding gestures or sounds), or elaborate on a message when cued "I don't understand", but he usually continued with a message rather than repeating concepts that were misunderstood.

CE tended to express more complex messages and more communicative turns with a wider variety of listeners when using the communication boards than without them. Baseline communication in social situations without the AAC boards showed an average of 6-8 communicative interactions in a 3 hour period, all with familiar listeners about present topics, and none beyond 4 conversational turns. Using the boards, CE frequently initiated conversations of 20+ turns with any listeners. In a representative social interaction, CE made minimal verbal responses when approached by an unfamiliar listener. When cued to use his boards, he initated multiple narrative topics and responded appropriately to the unfamiliar listener's questions, for a successful reciprocal interaction of over 15 minutes.

DISCUSSION

The AAC intervention has provided both an effective strategy to address some existing communication needs, and helped to broaden CE's communication modes to address future needs. Introduction of unfamiliar boards at this stage in his language progression takes advantage of CE's current gesture, verbal, and sight word recognition skills to understand the symbols. Later, he may be able to use the same (now familiar) boards to facilitate language comprehension and use with more resticted strategies.

Some of the goals of continuing communication intervention with CE include the following:

1. Construct a wallet version of communication boards to increase independence in use, including his self-generated cueing sheets for family information.
2. Include general context cues for preferred topics such as a U.S. map, clock, and pictures of salient places/people/events, in communication wallet.
3. Transcrbe essential story elements of his favorite topics, which can be added to the picture symbols to aid listeners in following the content of story.
4. Continue follow-up and family training, including facilitator training in familiar social groups.

REFERENCES

Bayles, K., Montgomery, E., Bryant, S., Wood, J. (1994). Progressive aphasia: Overview and case in point. Teleconference presentation (#14) and proceedings, January 19, 1994 , National Center for Neurogenic Communication Disorders, Tucson, AZ.
Beukelman, D.R. & Garrett, K.L. (1988). Augmentative and alternative communication for adults with acquired severe communication disorders. *Augmentative & Alternative Communication, 4* (2), 104-121.
Beukelman, D.R. & Yorkston, K.M. (1989). Augmentative and alternative communication application for persons with severe acquired communication disorders: An introduction. *Augmentative & Alternative Communication, 5*, (1), 42-48.
Bourgeois, M.S. (1992). Evaluating memory wallets in conversations with persons with dementia. *Journal of Speech and Hearing Research, 35* (6) 1344-1357.
Northen, B., Hopcutt, B., & Griffiths, H. (1990). Progressive aphasia without generalized dementia. *Aphasiology*, *4*, 55-65.
Poeck, K. & Luzzatti, C. (1988). Slowly progressive aphasia in three patients. *Brain, 111*, 151-168.
Sapin, L.R., Anderson, F.H., & Pulaski, P.D. (1989). Progressive aphasia without dementia: Further documentation. *Annals of Neurology, 25*, 411-413.
Weintraub, S., Rubin, N.P., & Mesulam, M-M. (1990). Primary progressive aphasia: Longitudinal course, neuropsychological profile, and language features. *Archives of Neurology, 47*, 1329-1335.

ACKNOWLEDGEMENTS

This research was supported in part by the Hattie B. Munroe Augmentative Communication Center and the Meyer Rehabilitation Institute.

Cynthia J. Cress, Ph.D., CCC-SLP
Meyer Rehabilitation Institute
600 S. 42nd. St.
Omaha, NE 68198-5450
(402) 559-5754

BEST COPY AVAILABLE

MOTIVATION AND THE MYOSWITCH:
THE DEVELOPMENT OF A MYOELECTRIC SWITCH FOR AAC

Isaac Kurtz*, Pearl Gryfe**, Mike Arnold**, Michelle Guttman**
*The Hugh MacMillan Rehabilitation Centre
**Assistive Technology Clinic, Sunnybrook Health Science Centre
Toronto, Ontario

ABSTRACT

Challenging clients often stretch the limits of the imagination in terms of developing creative technologies to allow access to communication devices and environmental controls. This paper will describe the development of an innovative myoelectric switch that enabled a client with virtually no movement save the slight contraction of the small muscles of the face, to communicate and produce complex documents through his computer. The client's role in the device selection process was pivotal in the success of this intervention. The clinical history of the client, myoelectric signal processing, and integration of the myoswitch with the client's AAC system will be reviewed.

BACKGROUND

The Client

An estimated 2.4 in every 100,000 people are affected by Amyotrophic Lateral Sclerosis (ALS)[1]. ALS, also known as Lou Gehrig's Disease and Motor Neurone Disease, is a progressive neuromuscular condition that leaves most of its victims totally paralyzed, unable to speak, and completely locked in. Our client is a 58 year old male who is a practicing judge of the Ontario Court of Justice. He was very athletic, and generally in good health until the spring of 1986 when he found he couldn't raise his arm to hang up his jacket or put on his judges robes. He was diagnosed with ALS in the spring of 1987 and a year later he was a complete quadriplegic and confined to a wheelchair. In 1989 (scarcely 2 years post diagnosis), he went into respiratory failure, and chose to be mechanically ventilated. At that point, alternative communication was required so that the judge could continue communicating. Although not able to preside over court proceedings, he decides over 60 cases a week on the basis of written affidavits and writes long explanations to further clarify his judgements. Thus, an effective writing tool as well as a face-face communication device was required. At the time, the device that was chosen by the client was an Epson Real Voice using single switch activation and Morse Code. Initially, many switches and access methods were tried including a pillow switch, touch plate and a modified sip and puff switch which required a biting action on a nipple attached via a sleeve on the switch. This switch was workable, however the nipple portion often broke down and was cosmetically unpleasant. This method proved to be limited as the judge's motor points continued to deteriorate. Although death from respiratory failure can be forestalled by artificial ventilation, motor neuron death continues and an end stage may be reached where there is little or no muscle movement[2].

None of the active muscles produced sufficient movement or force to activate a conventional mechanical switch. Due to the extremely limited physical abilities of this client, access to his communication device presented a significant challenge.

The Myoelectric Signal (MES)

Extensive experience at The Hugh MacMillan Rehabilitation Centre with the use of myoelectric signals to control the movement of prosthetic and orthotic limbs suggested that a myoelectrically controlled switch for communication might be an appropriate solution for this client.

The MES is the electrical signal produced by the contraction of skeletal muscle. The MES can be detected at the surface of the skin as a differential voltage between two electrodes placed above the contracting muscle. The MES is a Gaussian bandlimited signal with zero mean and a root mean square (RMS) amplitude of between 5 microvolts and several hundred microvolts. The amplitude is significantly attenuated by fatty tissue that lies between the muscle and the skin. Muscles that are located close to the skin surface, therefore, produce a stronger signal at the surface[3].

The RMS amplitude of the MES has been shown to be an optimal parameter for estimating muscle force for any particular muscle[4]. Due to the random nature of the MES, however, estimates of the signal RMS based on a finite time interval are prone to statistical error, or noise. In practical myoelectric control systems the RMS estimation time must be less than 100 mS to be imperceptible to the user[5].

To use the MES to activate a switch, an RMS estimate is compared to a predetermined threshold. This threshold must be set high enough to avoid inadvertent activation of the switch due to electrical noise in the environment from a.c. power lines and appliances, cross-talk from other muscles and inadvertent low-level activation of the controlling muscle. In practical myoelectric control systems this threshold is rarely set below 10 microvolts. For a low amplitude MES, setting the activation threshold involves a compromise between the conflicting requirements that the threshold be high enough to avoid error due to external noise and low enough to avoid errors due to the inherent statistical noise of the signal.

In prosthetic control systems, hysteresis is often introduced to alleviate errors due to noise, ie. a relatively high threshold is required to activate the system while a threshold that is typically half that level is used to deactivate the system once it has been activated.

While the introduction of hysteresis works well in prosthetic applications, some modification of the approach is required for application to augmentative communication. The threshold levels used in commercially available prosthetic control systems assume that the user is completely relaxing the controlling muscle between activations. In AAC applications, and particularly in a Morse Code system, this requirement would significantly slow down the user. The setting of hysteresis thresholds in this application needs to take into account the rate and level of the user's signals during the rapid contract/relax cycles of Morse Code entry.

OBJECTIVES

The evolution of the myoelectric access switch involved intensive input by the client and had to satisfy the following objectives:
1) **Ease of Activation and Flexibility.** Due to his severe impairments, the preferred solution was a switch that could be activated by any of the client's remaining voluntary movements.
2) **Comfort.** It was necessary that the client be able to sleep with the switch in place, as it was connected to a call bell to alert the nurse at night when necessary.
3) **Cosmesis.** The client had expressed concern about the appearance of the modified sip-and-puff switch and wanted an unobtrusive solution, especially for social occasions.
4) **Portability.** Despite his disability, the judge leads an active working and social life. The new switch needed to be used at work, around the home, in bed and on vacations. A switch that could be mounted on the client as opposed to a wheelchair-mounted switch was needed.
5) **Reliability.** The client uses the switch extensively to converse and to write documents and letters. We estimate that with Morse Code the client activates the switch between 5000 and 10,000 times a day, or several million times per year.
6) **Compatibility with Morse Code.** The client was an efficient Morse Code user at the time that the request was made. Piezoelectric switches that do not allow the user to control the timing of switch activations would not be suitable for this application.

APPROACH

None of the alternative switches that had been tried with this client met all of the objectives outlined above. At the request of the client and his wife, we explored the possibility of a myoelectrically controlled switch to meet these objectives.
A myoelectric signal of approximately 25 microvolts RMS was detected on the medial surface of the client's left hand and on some of the client's facial muscles. An integrated electrode/amplifier assembly from Otto Bock was used for MES detection in order to eliminate noise artifacts due to cable movement. The assembly is small (2.5 cm x 1.5 cm) and could be attached to the client's hand or face with tape.

It was empirically determined that the client could operate Morse Code using a 20 microvolt threshold to activate the switch and a 15 microvolt threshold to deactivate the switch.

The output of the threshold detection circuitry was used to operate an electromechanical relay with a life expectancy of 1,000,000 activations. The relay provides the added advantage of auditory feedback which is used by the client to ensure that the switch is operating properly.

RESULTS AND DISCUSSION

The client operated the myoelectric switch with his left abductor digiti minimi muscle for approximately one year. Eventually, this muscle weakened and was no longer reliable for use in activating his communication device. The only consistent motor points left to this client were the small muscles of the jaw and the frontalis muscle. The electrodes were moved from the client's hand to his cheek. This represented a compromise on the original objective of cosmesis but it was imperative that this client have access to a reliable means of communication in order to function in his personal and professional milieus.

Although the myoelectrically controlled switch achieved the objectives outlined above, the issue that was not completely resolved was that of reliability. Because of the constant use of the device and frequent movement of the client, the reliability of cables connecting the client's electrodes to the signal processing circuits has been a significant concern. An ideal solution to this problem would be a wireless connection between the electrode and circuitry. We are currently investigating the technological feasibility of this idea. In addition, battery power consumption was a concern since the unit was used day and night. To address this issue, the design has been recently modified to incorporate a latching relay that requires minimal power while at rest. The reliability of the original relay, rated for 1,000,000 activations, proved to be insufficient for this client. A latching relay with 10 times that rating has replaced the original one.

Another outstanding issue was the client's AAC system that does not represent the most current and advanced technology. Recently the client has chosen to switch from Morse Code to a scanning system, as he found that the number of activations required for Morse Code use was exhausting him. With this change, the team has begun to explore rate enhancement techniques to improve the efficiency of the client's face-to-face and written communication.

In conclusion, in spite of this client's devastating disease he has refused to give up and has found the motivation, the resources and the right expertise to help him overcome his communication barriers. The custom development of the myoelectric switch met this client's needs where commercial switches could not. Successful integration of the myoswitch required careful matching of the individual's needs to his environment, an understanding of the scope of the disability and an interdisciplinary team approach.

REFERENCES

1. Hudson A.J., ALS: Concepts in Pathogenesis and Etiology, University of Toronto Press, Toronto, 1990.

2. Bromberg, M.B., Progression of ALS in Patients on Artificial Ventilation, in: 5th International Symposium on ALS/MND, Noordwijk, Holland, 1994.

3. Basmajian J.V., De Luca C.J., Muscles Alive (5th edition), Wiliams and Wilkins, 1985.

4. Hogan, N., Mann R., Myoelectric signal processing: Optimal parameter estimation applied to electromyography, Part I: Derivation to the optimal myoprocessor, IEEE Transactions on Biomedical Engineering, 27:382, 1980.

5. Parker P.A., Scott R.N., Myoelectric control of prostheses, in: CRC Critical Reviews in Biomedical Engineering, 13:4, pp.283-310.

ACKNOWLEDGEMENTS

Funding for this project was provided in part by the ALS Society of Metropolitan Toronto.

Isaac Kurtz
Electronics Coordinator
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Rd.
Toronto, Ontario, Canada M4G 1R8
Telephone: 416-424-3855 ext.505
Fax: 416-425-1634
Email: hmrcelec@gpu.utcc.utoronto.ca

DEVELOPING AN INTERFACE FOR AN AUGMENTATIVE COMMUNICATION DEVICE WITH MULTIPLE VOCABULARY SELECTION MODES

Clifford A. Kushler
Prentke Romich Co., Wooster, Ohio

ABSTRACT

An augmentative communication (AAC) device has been enhanced with a sophisticated word prediction (WP) system. Previously, the vocabulary modes available consisted of semantic compaction (SC) and traditional spelling. The word predictor is designed to be flexible, with a large number of features which can be customized according to the system operator's preferences. An interface has been developed which allows both rate enhancement techniques (SC and WP) to be utilized simultaneously without requiring any additional keystrokes. This approach maximizes the efficiency of SC for accessing frequently used words in a "core" vocabulary, and WP for accessing less frequently used "fringe" vocabulary [3].

BACKGROUND

Devices based on an SC encoding system such as Minspeak™ support fluent, automatic access to a substantial core vocabulary of frequently occurring words (such as WordsStrategy™). However, it is not practical to expand such systems to provide icon-based access to a much larger "fringe" vocabulary of infrequently occurring words. Attempting to incorporate a much larger vocabulary would require expanding the number of icons used, increasing the length of the sequences, or sacrificing the memorability of the sequences. Any of these changes would seriously compromise the effectiveness of SC in providing automatic and rapid access. Provided that the system operator has adequate spelling skills, an appealing alternative approach is to integrate both WP and SC in a multi-modal system to provide simultaneous access to fringe vocabulary items via WP and core vocabulary via SC.

Preliminary work on corpus analysis and vocabulary selection for such a system has already been performed [3]. A morphologically-based WP system is being developed in which the prediction list will show only root forms of words as each letter is typed. When the desired root form appears and is selected, the prediction window immediately displays the appropriate inflected forms of the root word which can then be selected. If the root form itself is desired, the system operator can begin spelling the next word without making a second prediction choice. Such a two-step morphologically-based prediction system offers a number of significant advantages, including: helping maximize the coverage of a given size lexicon; presenting the system operator with a consistent interface for selecting similar morphological forms of different words; making the most of a limited-size prediction list; and addressing the frequently observed problem in which, although one or more forms of a given root word may appear in a prediction list, the desired form may not appear until a number of additional letters are typed, and sometimes may not appear at all [1].

STATEMENT OF THE PROBLEM

One of the major challenges to be met in implementing such a system is to develop a user interface that seamlessly integrates these two rather disparate approaches to vocabulary selection. In order to reap the maximum benefit from the integration of the two systems, it is also necessary to provide some new features to control the operation of the WP system. Tools are needed for managing both the SC vocabulary and the WP dictionary, particularly with respect to where these overlap. These tools need to be able to configure the system for maximal efficiency for a variety of system operators, and to accommodate the changing needs and abilities of an individual operator.

The interface is further constrained by the need to operate on a device with a 128-location static overlay, and an 8-line, 40-character LCD display. WP systems in general require dedicated keys to be defined which are used to select words from the prediction window. In the keyboard overlay for the WordsStrategy™ Minspeak Application Program™ (MAP), all but three locations have been assigned icons, special functions, or letters (including bigrams and trigrams). This overlay has been developed and finely tuned to provide efficient access to both spelling and the core Minspeak™ vocabulary. It is highly unlikely that this overlay could be significantly restructured without having a negative impact on the overall efficiency of WordsStrategy™. Moreover, this would certainly be undesirable for the many system operators who have reached a level of automaticity using the current overlay. Thus, defining the means by which predicted words are selected in the multi-modal system is one of the important challenges to address.

RATIONALE

In combining two rate enhancement systems, it is important that neither is negatively affected, and that both can be optimally managed. For example, it may often be desirable to exclude items in the core vocabulary from appearing in the fringe vocabulary in order to maximize the efficiency of WP in accessing these fringe words. Alternatively, WP might be used to access words in the core vocabulary more rapidly than simple spelling, so that the icon sequence for the word could then be automatically shown to the operator as a method of self instruction. Once learned, such vocabulary items could be automatically eliminated from the predictor.

Properly combined and integrated, the combination of these two rate enhancement techniques in a single system can result in a significant improvement of both. Such a system can provide relatively rapid access to infrequent and even rarely occurring vocabulary without detracting from the method used to quickly access the most commonly used core vocabulary.

DESIGN / DEVELOPMENT

One major constraint to be met in the development of an interface for the multi-modal system is that both rate enhancement techniques are simultaneously active and available, and that no additional keystrokes are required to switch between them. Moreover, a single keyboard with a static overlay must be used (such as WordsStrategy™) which includes a large number of keys that are associated with both an icon for selecting icon sequences and a letter (or a letter bigram or trigram) for spelling.

This constraint is largely satisfied by making use of the automatic mode selection feature (Auto-Spell™ mode) in existing SC based systems. With each key input, the system monitors and displays which icons have been selected and which icons can follow in existing encoding sequences for items in the core vocabulary accessed via SC. At any point where the icons generated by a selected key sequence fail to match any existing icon sequence, the sequence of key activations is automatically re-interpreted as spelling and the corresponding letters are generated for the sequence of selected keys. The system then stays in spelling mode until a space is typed, when it automatically reverts to Minspeak™ mode. In the multi-modal system, the word predictor can be invoked starting with the first key activation in each sequence, interpreting each activation as the corresponding letter(s) even before actually switching to spelling mode. For example, activating the key associated with the icon ***TIME*** and the letter ***t*** would show the activation of the icon in the display buffer, light the LEDs of all keys associated with icons that follow ***TIME*** in existing sequences, and generate a prediction list of words starting with the letter ***t***. Thus, a vocabulary item may be retrieved using SC, WP, or simple spelling with no additional keystrokes to select the mode being used.

A second constraint to be met, especially in the case of previously established and widely used MAPs™ such as WordsStrategy™, is that the number of keys that must be dedicated to controlling or operating the WP system must be kept to an absolute minimum, including keys for selecting word choices offered in the prediction window. A number of keys in WordsStrategy™ are dedicated to various system functions (e.g. editing keys) that are seldom if ever needed while selecting icons or spelling new text. The device's macro language has been enhanced to include conditional control statements. The keys previously dedicated to editing can now be programmed to test whether a word is currently displayed in the corresponding prediction window slot. If so, the LED on that key will flash (at a user-selectable rate) to indicate that, if depressed, the corresponding word will be selected. When no word appears in the window slot, the LED does not flash and selecting the key performs the assigned editing function. In those cases where editing functions are needed but the prediction window is on-screen and the desired function keys are flashing, an additional keystroke is required to temporarily turn off prediction. All keys then revert to their assigned editing functions until prediction is re-enabled. Thus, the only additional key required is one to toggle the prediction window on and off.

In order to maximize the synergistic improvement that can be gained for both rate enhancement techniques through combining them, it is necessary to add some additional management tools to the system. In a case where the system operator has already learned all of the icon sequences for the SC core vocabulary, the efficiency of the word predictor for accessing less frequently used words will be significantly enhanced if all of the common core words are disabled as candidates in the predictor. On the other hand, if a less experienced user is still in the process of learning many of the icon sequences, these common core words could be first accessed using the word predictor. Each time a word is selected via the predictor that is included in the core vocabulary, the icon code sequence tutor [2] can be automatically invoked, displaying the icon sequence for the word at the bottom of the screen, and optionally flashing the keyboard LEDs of the encoding icon keys in sequence. The word predictor could thus be used to help the operator learn the core icon sequences. The system can be set to automatically disable a word from the predictor once it has been retrieved through its icon sequence a predetermined number of times. Similarly, if a word is not stored under an icon sequence but is repeatedly used via the predictor, after a predetermined number of times the operator can be prompted to see if the word should be added to the core vocabulary. Even when a core word has been disabled from the predictor, the system can be configured so that each time the word is selected via its icon sequence, the predictor can display the morphologically derived forms for that word in case an unusual form is desired.

Another management feature that has been added to the system is the ability to categorize each word in the predictor as belonging to one of 16 user-definable topic areas. Different topics can then be enabled or disabled, or it is also possible to change their relative priorities as candidates to appear in the prediction window. Words can be assigned to topics by typing them individually (selecting from the predictor if desired), selecting groups of words according to an icon sequence prefix or suffix, or by reading in a text file from a computer. Once assigned, topic membership may also be "locked" for chosen topics.

New words may also be added to the prediction dictionary. With 20,000 root forms and over 50,000 inflected forms, it is expected that the majority of the words added will be proper nouns, where the only inflected form required is the possessive. For other parts of speech, an approach is used similar to that suggested by Hunnicutt [1]. The new word is first entered, and then the operator is prompted to enter a word that is similar in terms of its part of speech, terminal spelling, and usage. The system then applies the morphological derivation rules for the proposed similar word to the new word, displaying the resulting inflected forms. If the operator approves, the new word is entered with that set of derivation rules. Otherwise, the operator can try again or choose to simply enter the word as an uninflected root form.

Other aspects of the interface that can be configured include: the number of display slots in the prediction window; the number of slots filled on the basis of recency, frequency, or a fixed pattern; whether words are displayed in upper or lower case; and whether the window is displayed in inverse video on the LCD.

EVALUATION

Although formal beta-testing of the system described in this paper has not yet begun as of the time of writing, a working prototype has been demonstrated to a large number of professionals, including several speech language pathologists specializing in AAC, and three system operators. Much useful feedback has been received, and improvements and refinements continue to be implemented. One area in which substantial changes are being made is in the auditory feedback provided for operators with visual impairments. The overall response has been extremely positive. Actual beta-testing is expected to begin in April of 1995.

DISCUSSION

The purpose of the multi-modal system is to provide easy, rapid and efficient access to a large fringe vocabulary without detracting from the ability to quickly and automatically access the core vocabulary. Important design goals met in the system include: it has been implemented on a single keyboard with a static overlay; it functions transparently, promoting the development of automaticity in its use; vocabulary management tools help maximize the efficiency of both rate enhancement modes; and no additional key actuations are required to switch between modes.

REFERENCES

1) Hunnicutt, S., Bertenstam, J., and Raghavendra, P. (1994) A Morphologically-Based Word Predictor for Swedish. *Proceedings of the RESNA '94 Annual Conference*, pp. 106-108. Nashville, TN: RESNA.
2) Kushler, C. A. (1992) Providing On-line Support in an Augmentative Communication Device. *Proceedings of the RESNA International '92 Conference*, pp. 113-115. Toronto, Canada: RESNA.
3) Nyberg, E. H., Baker, B. R., Kushler, C. A., and Higginbotham, D. J. (1994) Corpus Analysis and Vocabulary Selection for Word Prediction in a Multi-Modal System. *ISAAC '94 Conference Book and Proceedings*, pp. 551-553. Maastricht, The Netherlands: ISAAC.

ACKNOWLEDGMENTS

I would like to acknowledge the efforts of a number of people in developing the system: Arlene Badman, Bruce Baker, Dave Hershberger,Jeffrey Higginbotham, Jeffrey Micher, Doug Miller, and Eric Nyberg.

Clifford A. Kushler, Ph.D.
Director of Research, Prentke Romich Co.
1022 Heyl Rd., Wooster, OH 44691
Tel: (216)262-1984 ext. 220 Fax: (216)263-4829
cak@prentrom.com

A LEXICAL DATABASE FOR INTELLIGENT AAC SYSTEMS

Wendy M. Zickus, Kathleen F. McCoy, Patrick W. Demasco, and Christopher A. Pennington
Applied Science and Engineering Laboratories, University of Delaware/A.I. duPont Institute
Wilmington, Delaware

Abstract

A typical non-computerized dictionary contains a wide range of information about words such as spelling, pronunciation, morphology, parts of speech, definitions, synonyms, antonyms, and other language features. The knowledge available in these dictionaries would be very useful for an intelligent AAC System; for instance, an AAC System that applies Natural Language Processing (NLP) in order to expand telegraphic messages.

This project focuses on the development of a comprehensive language database that integrates several complementary lexical resources with a single unified programming interface. This database will be used in the development of several systems that employ natural language parsing and generation techniques.

Background/Motivation

The use of Artificial Intelligence (AI) and Natural Language Processing (NLP) techniques in the development of AAC systems and devices continues to grow both in research laboratories and, more recently, in commercial products. The use of AI/NLP methods in any application area often requires significant language knowledge such as syntax and semantics (1). Within AAC, the need to support relatively unconstrained message production (in contrast to something such as a database query) requires that this knowledge be broad as well as detailed.

One example of an intelligent AAC technique is *Compansion* (2), an approach that takes telegraphic input from a user and expands it into a syntactically and semantically well-formed sentence. The Compansion technique assumes a communication system based on words, pictures, or icons (i.e., non-spelling) and attempts to enhance the user's message production rate[1] by requiring only the selection of content words. One advantage of such a system is that it reduces the need to represent morphological information (e.g., verb inflections). This is potentially very beneficial for systems that use picture-based representations.

A major component of the Compansion system is the semantic parser which takes a set of words and attempts to fit these items into a well-formed semantic structure thus determining the intended meaning. In the current implementation, processing is non-incremental; all of the input words are taken together and a semantic representation is created which best accommodates the set of words as a whole. Generally there will be at most one word identified as the main verb in the input words; the parser must determine which semantic role is being played by the other words. Consider the processing of the input *"John break hammer"*. Once break is identified as the verb, the parser must decide which word of the input represents the agent (i.e., person or thing doing the action), which represents the theme (i.e., thing being acted upon), etc...(2). This information is represented in the semantic parser in the form of a case frame[2] for *break* (a simplified form of which is shown below):

verb: *break*
agent: [[human 3] [animate 2] [ergative 2]]
theme: [[physical 3] [object 1]]
instrument: [[tool_box 3] [tool 3] [solid 1]]
goal: [[human 3]]
beneficiary: [[human 3][organization 2]]
location: [[place 4]]

The above frame indicates that the agent role is preferred to be filled by a human, but that any animate object or ergative object (e.g., a car) would also be acceptable. The theme role is preferred to be filled by a physical object, but an abstract object could also serve as a filler (although less preferred).

The basic idea of the semantic parser is to fit the non-verb words of the input into the case frame in the best way possible. In order to do this, the semantic parser must access type-information associated with each word. For instance, it must be able to tell that *John* is a human and that *hammer* is not a human but a physical object. With this information the semantic parser can reason about the words of input and generate the sentence *John breaks the hammer.*

Statement of the Problem

One of the limitations of AAC devices today is the size and information available in their dictionaries.

---

1. While the Compansion techniques has been primarily described as a rate enhancement technique, it also has potential applications in helping users learn how to produce grammatical sentences

2. A semantic representation developed by Fillmore (3).

While some may contain an adequate amount of words, none of them contain the sufficient information needed to do semantic and syntactic reasoning. For instance, the word information needed for the semantic parser described above is not generally available in current systems. In addition, while there is substantial interest in the development of natural language interfaces within the general software community, there currently do not exist any lexical databases that provide both a broad coverage (in terms of numbers of words) and sufficient depth of information (e.g., case frames) for individual words (1).

Fortunately there are a variety of lexical resources available both commercially and from a variety of research laboratories. It would be advantageous to integrate these resources so that they could complement each other. This approach would allow a developer to extract desired information in a consistent, understandable and functional manner. This is the idea behind the Language Access Database (LAD).

Approach

The approach to designing LAD has been to create an implementation with C++ and Lisp[1] interfaces that allows a programmer to access several different databases (or lexical resources). The programmer is given as much or as little control as they need. For instance, they can simply query LAD about the frequency of a word and LAD will return the frequency rating found for the most generally accepted meaning of that word in some default corpus. Alternatively, if the programmer prefers, they can specify a specific "sense" of the word they are interested in and specify which corpora they would like to use.

LAD accesses several different lexical resources. The most unusual of these is an on-line dictionary/thesaurus created at Princeton University called WordNet (4). It is WordNet that contains much of the semantic information needed for intelligent AAC applications.

WordNet

At first, one might think that a computer-based lexical resource ought to be set up just like a traditional dictionary. However, this approach has some limitations. One such shortcoming is that the information stored with a word is often incomplete. When one looks up a noun, for example *platypus*, one learns that it is a semiaquatic, egg-laying mammal, but unless one is an expert on mammals, there is no way other than by looking up mammal to find out if the *platypus* has hair. Dictionaries are ordered alphabetically and not grouped semantically, therefore such searches can be cumbersome. This weakness in contemporary dictionaries demonstrates one of the major strengths of WordNet: its semantic and lexical relations. By using the WordNet on-line lexicon, it is easy to discover the attributes of a given noun by traversing the semantic relations of its superordinate term (i.e., its "parent" or category).

Another deficiency in contemporary dictionaries is the lack of information about coordinate terms (i.e., "sister" terms). Someone looking for information about other mammals would be forced to search the dictionary from beginning to end looking for terms that are classified as mammals. The prototypical lexical entry for a word points to its superordinate term, not laterally to its coordinate terms or downwards to its hyponyms (i.e., its "children" or subordinate terms). Again, these weaknesses are strengths of WordNet: its ability to reach related terms easily through its direct links to superordinate, coordinate and hyponymic terms makes searches of such information routine.

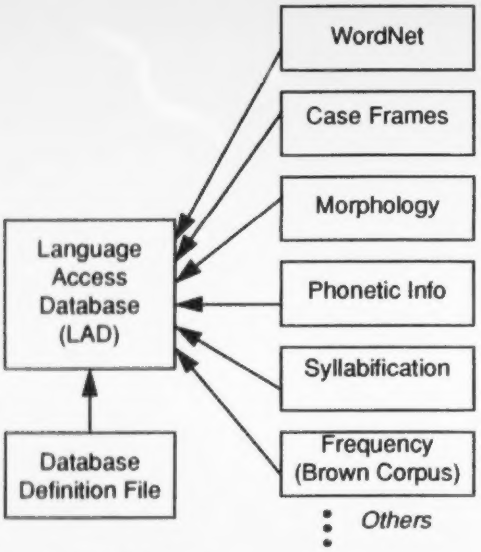
However, there are weaknesses in using only WordNet. If someone desires phonetic information, morphological forms of a word, information on non-noun/verb/adjective/adverb terms, proper nouns, or information on function words they need to go to another source. WordNet serves as a good foundation for developing a multi-purpose linguistic tool. Its breadth of coverage and sense information provides a wealth of lexical information. LAD is intended to utilize this knowledge and enhance it by using other database sources to create a centralized interface system that facilitates access to language.

Secondary Databases

Some of the other databases that LAD can access include an internally developed verb case frame database (where verb frames such as the one from our previous example are stored), a morphology database, a database containing phonetic information, a syllabification database, and statistical databases (e.g., frequency) derived from the Brown corpus and the Carterette corpus. The morphology database is important to systems like Compansion. For instance given the input *"John eat many apple"*, the system needs to be able to reason about the word *many* and change *apple* to *apples*. If the tense is present it must change *eat* to *eats* and if the tense is past, change *eat* to *ate*. Phonetic information is important for systems that need to generate speech. The statistical databases are useful for traditional AAC techniques such as word prediction.

---

[1] In our laboratories, we often use Lisp to develop prototypes and C++ to for commercial application development.



Integration of Resources

The figure above shows the overall structure of LAD. One important function of LAD is the integration of multiple lexical resources. These resources are shown on the left part of the figure. The architecture is extensible in that new lexical resources can be added without modification to the database engine. This is possible through the database definition file which defines the set of lexical resources, their location, and what attributes (e.g., frequency) they contain. Secondary lexical resources are defined as files where each record contains the word, its attribute, and an optional WordNet sense specification. The coordination of secondary databases with WordNet senses is one of the major benefits of integration. For example, the noun "bow" would be pronounced differently if it is a ornamental ribbon compared to the front of a boat.

LAD is intended to be used in several different applications. Its functionality lends itself to be a useful tool for abstracting various types of word information required by different systems. In some cases this information might not be explicitly available. For example, in systems that need verb frame information, there may be some verbs that do not have frames (e.g., pummel). By default, LAD currently retrieves a verb frame from a secondary database. In the case where the verb is not represented in the secondary database, a case frame is generated by first searching synonyms of the verb from WordNet (e.g., crush) and then checking in the secondary database for these synonyms. If that search still fails, then a case frame is generated based on the WordNet verb frame which, although it lacks detail (e.g. Somebody ---s something), would still be useful in a system that was designed to be linguistically robust.

Discussion

LAD is designed to interact with multiple lexical databases in a transparent manner. The user/system treats LAD as a single dictionary. The resulting system will be a useful tool for various AAC applications. Other applications that could benefit from LAD include a speech synthesizer needing pronunciation information and a syntactic-based word predictor using morphological information to predict correct verb forms. It is currently being tested with a semantic parser based on the reasoning principles used in Compansion. A number of enhancements are being planned that will increase the ultimate utility of the tool. This includes a compiler that will produce a more compact version of the database based on an input list of words. This will reduce the overall memory and disk space requirements when used in a practical system. In addition, while LAD is intended to be primarily used by programmers, it will also be necessary for non-technical people to enter new information into the system. For this a front-end program will be developed that will help facilitate this process.

References

[1] McHale, M. & Crowter, J. (1994) Constructing a Lexicon from a Machine Readable Dictionary. *Army Rome Laboratory Technical Report*, #RL-TR-94-178, Rome Laboratory, Griffis AFB, NY.

[2] McCoy, K., Demasco, P., Jones, M., Pennington, C., Vanderheyden, P., and Zickus, W. (1994). A communication tool for people with disabilities: Lexical semantics for filling in the pieces. In *Proceedings of ASSETS '94*.

[3] Fillmore, C. J. (1977). The case for case reopened. In P. Cole and J. M. Sadock, editors, *Syntax and Semantics VIII: Grammatical Relations*, pp. 59-61, Academic Press, New York.

[4] Miller, Beckwith, Felbaum, Gross, Miller (1990). Introduction to WordNet: An On-line Lexical Database, *CSL Report 43*, Revised March 1993.

Acknowledgments

This work has been supported by a Rehabilitation Engineering Research Center Grant from the National Institute on Disability and Rehabilitation Research of the U.S. Department of Education (#H133E30010). Additional support has been provided by the Nemours Research Programs.

Wendy M. Zickus
Applied Science and Engineering Laboratories
1600 Rockland Road, P.O. Box 269
Wilmington, Delaware 19899 USA
Internet: zickus@asel.udel.edu

Validating Quantitative Models of User Performance with Word Prediction Systems

Heidi Horstmann Koester and Simon P. Levine
Rehabilitation Engineering Program, Graduate Bioengineering Program
University of Michigan

Abstract

Three model implementations were developed to simulate user performance with a word prediction system. Model simulations were tested against the actual performance of able-bodied and spinal cord injured subjects. Models 1A and 1B shared a structure which represented performance as a linear combination of two user parameters, keypress and list search time, while Model 2 used a revised model for list search time. For Model 1A, user parameter values were determined independently, while Models 1B and 2 used parameter values derived from subjects' data. The average errors for Models 1A, 1B, and 2 in simulating subjects' word entry times were 27%, 16%, and 14%, respectively.

Introduction

Models of user performance with AAC and computer access systems have the potential to help practitioners design, configure, and recommend more appropriate systems to meet users' needs. A key to realizing this potential is understanding the accuracy obtainable with quantitative models. This paper reports on the development and validation of quantitative models of user performance with word prediction systems.

The models developed in this work are based on the Keystroke-Level Model, a technique which originated in the field of human-computer interaction [1,2]. This technique provides a means of identifying the component actions that a user must perform for a particular task. By attaching times to these activities, the overall task time can be predicted.

Within the Keystroke-Level Model technique, there are a variety of specific methods. "Keystroke-Level" means that the model represents events in the range of 100 ms to a few seconds. The way in which the overall task is broken down into these short duration component events is the *model structure*, and is a choice of the modeler. A second dimension on which models can vary is the source of *user parameter values*. Each model structure yields a parametric equation for task performance time. Parameters representing the user can be drawn from independent sources, such as previous human performance studies, or they can be derived directly from subjects' performance data. Independent models are easier to apply and potentially more generalizable than data-driven models, but they are typically less accurate. For tasks such as text editing and spreadsheet use, errors reported for models with independent structure and parameters average 52.2%, with a range of 24 - 137%. For models whose structure and/or parameters have been derived from subject data, average error is 16.6%, with a range of 4 - 33% [3]. To begin to assess the suitability of models for AAC applications, we need to measure the accuracy for a representative task under different model implementations. The three model implementations used in this work are:

- Model 1A. Structure and parameters are independent of validation data.
- Model 1B. Same structure as Model 1A; user parameters are derived from validation data.
- Model 2. Structure and parameters are derived from validation data.

Methods

Empirical Data for Model Validation. Fourteen subjects transcribed text with and without a word prediction feature for seven test sessions. Text was unique in each session. Eight subjects were able-bodied and used mouthstick typing. Six subjects had high level spinal cord injuries and used their usual method of keyboard access. Two of the spinal cord injured subjects used a mouthstick for typing, and the other four used hand splints. Each subject was assigned to use one of two word prediction strategies, to provide a behavioral basis for the model structure. The rule for Strategy 1 was to search the list before every selection. The rule for Strategy 2 was to choose the first two letters of a word, then search the list before each subsequent selection.

Dependent measures of subject performance included overall text generation rate, time to enter each individual word in a session, and time to select each item. Model simulations of any of these measures are possible. Overall session performance is the most clinically relevant measure, but simulations across an entire session may capitalize on cancellation of positive and negative errors, leading to an overly optimistic estimate of model accuracy. This paper focuses on simulations of word entry times, to reduce the effect of fortuitous error cancellation while maintaining some clinical relevance.

Validation of Word Prediction Model

Structure of Models 1A and 1B. The structure of Model 1 represented the task of text entry as a simple sequence of keypresses and list searches. The time for each item selected in a session was modeled as a keypress-only (t_k) or a list search-plus-keypress ($t_s + t_k$), depending on the strategy rules followed by the subject. Keypress time was assumed to be independent of the key's position, and list search time was assumed to be independent of the search context. An equation for each word's entry time was formed by summing the model times for each selection made for the word. This process was performed for each word entered by each subject in every test session.

Structure of Model 2. With Model 2, keypress time continued to be represented by a single parameter value, and the representation of list search time was refined. The general strategy used for the refinement was to identify candidate factors that might influence list search time, determine the relative strength of each of these factors using regression analysis, and create a new model of list search time to reflect the influence of the strongest factors [3].

Two factors examined for their influence on list search time were a serial search process and anticipation of list contents. Variables reflecting the context of the search were chosen to represent these factors. For example, variables related to serial search were the position of the target word and the length of the list, for successful and unsuccessful searches respectively. The strength of the candidate predictor variables was evaluated by a series of multivariate and bivariate regression analyses, performed for each subject's set of list search times in Session 4. (Only one session was examined due to the large number of analyses involved.)

User Parameters, Model 1A. For Model 1A, keypress and list search times were determined from previous studies reported in the literature. The best available source for keypress times was a study of able-bodied individuals who typed with mouthsticks for 30 typing tests [4]. The average typing speed for the 30 tests was fit to a Power Law curve, and the resulting fitted values used for keypress time ranged from 1.15 to 1.01 seconds across Session 1 through Session 7.

Independent values for list search time were derived from a composite of studies on list search [3,5]. These studies were used to establish an appropriate value for search times in the 1st and 7th test sessions. A Power Law curve was then fit between the estimates for Sessions 1 and 7 to determine values for the intermediate sessions. The resulting values ranged from 1.0 to 0.5 seconds across Sessions 1 to 7.

User Parameters, Model 1B. For the Model 1B simulations, user parameter values for each subject were derived directly from the subjects' performance data, using the subtractive methods employed in other Keystroke-Level Model studies [1,2]. The keypress time during word prediction use (t_k) was calculated by averaging the times for all keypress-only selections in the session. The list search time (t_s) was derived by subtracting one t_k from the time recorded for each list search-plus-keypress selection, then averaging the resulting time differences. Average keypress times from Session 1 to Session 7 ranged from 1.05 to 0.89 seconds for able-bodied subjects, and from 0.97 to 0.76 seconds for spinal cord injured subjects. Average list search times from Session 1 to Session 7 ranged from 0.66 to 0.47 seconds for able-bodied subjects and from 1.17 to 1.14 seconds for spinal cord injured subjects. (An analysis of the differences between able-bodied and spinal cord injured subjects has been presented elsewhere [5].)

User Parameters, Model 2. The keypress times used for Model 1B were also used for Model 2. New values for list search time were calculated for each list search-plus-keypress selection using the regression equations derived in the revision to the model structure.

Simulations and Validation. Simulations of word entry times were performed for each subject-session combination by substituting the user parameter values into each word's model equation. For Model 2, simulations were performed for Session 4 only. Model error scores were computed for each subject-session combination by averaging the absolute value of the percent difference between the actual and simulated word entry times. Statistical analyses were performed using a repeated measures ANOVA, with between-subjects factors of strategy and presence/absence of spinal cord injury and within-subjects factor of test session. Significance of all statistical tests was judged at a familywise p-value of 0.05.

Results

Figure 1 summarizes the error of each Model in simulating subjects' word entry times, collapsed across the seven test sessions. Average error for able-bodied (AB) and spinal cord injured (SCI) subjects are shown separately, in addition to the average error across all subjects (ALL). Bars indicate one standard deviation.

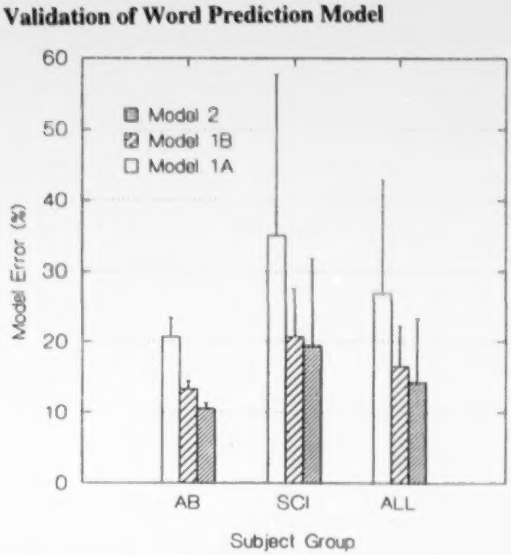


Figure 1. Average error of Models 1A, 1B, and 2, for simulations of word entry times.

For Model 1A, whose simulations were completely independent from subject data, the average error was 26.9% across all subjects. Model error decreased significantly when empirically-derived user parameters were used, as illustrated by the 16.5% average error obtained with Model 1B. Revising the model representation of list search time yielded a small but statistically significant improvement in accuracy, as Model 2 had an average error of 14.3%.

The trends in the results were similar for able-bodied and spinal cord injured groups, but model error was generally higher and more variable for the subjects with SCI as compared to the able-bodied subjects. The difference in model error between subject groups, however, was not statistically significant.

Discussion and Conclusions

The results of these simulations compare very favorably to accuracy reported in previous applications of Keystroke-Level Models, which suggests that the modeling technique is as applicable to AAC and computer access systems as it is to other human-computer interfaces. A companion paper [6] illustrates how such a model can be used to examine performance across a range of usage conditions.

Manipulating the modeling dimensions of structure and user parameters had the expected effects. With respect to model structure, the refined representation of search time in Model 2 did improve model accuracy. However, the amount of improvement was quite small relative to the effort involved in the structural revisions. It is possible that a revised representation of keypress time may have led to additional gains in model accuracy.

With respect to user parameters, empirically-derived values yielded fairly large improvements in model accuracy, particularly for spinal cord injured subjects. This reinforces the intuition that variation between user parameter times must be accounted for in an accurate user performance model, particularly for the AAC user population.

While the overall results were encouraging, the model has been validated on only a relatively small subset of possible users and systems that may be of interest. It will be important in future work to assess the accuracy of the model for users who are word prediction experts and those who have more variable motor control and/or cognitive impairments. Additionally, imposing particular strategy rules on subjects influenced the accuracy obtained, which suggests that these results are most applicable to a clinical situation in which the user consistently employs a particular method of using the list. Research is currently being performed to determine the suitability of this approach for modeling users' natural strategies.

References

1. S. Card, T. Moran, A. Newell. *The Psychology of Human-Computer Interaction*. Hillsdale, NJ: Erlbaum Associates, 1983.
2. J.S. Olson, E. Nilsen. "Analysis of the cognition involved in spreadsheet software interaction," *HCI*, 3:4, 309-350, 1988.
3. H.H. Koester. "User Performance with Augmentative Communication Systems: Measurements and Models," Doctoral Dissertation, University of Michigan, 1994.
4. S.P. Levine et al. "A comparison of mouthstick and Morse code text inputs," *AAC*, 2:2, 51-55, 1986.
5. H.H. Koester, S.P. Levine. "Text entry performance with a word prediction interface," *IEEE Trans. on Rehab. Engin.*, 2:3, 177-187.
6. H.H. Koester, S.P. Levine. "Simulations of user performance with word prediction," submitted to *RESNA '95*.

Acknowledgments

This research was supported by the National Science Foundation, Rackham School of Graduate Studies, and the U-M Rehabilitation Engineering Program.

Heidi Horstmann Koester, Ph.D.
1C335 University Hospital
Ann Arbor MI 48109-0032
Internet: hhk@umich.edu

INTEGRATED ACCESS TO POWERED MOBILITY, TILTER, COMPUTER, AND ENVIRONMENTAL CONTROL

Bert Shire, John McAlpine, Linda Petty, Chris Ridpath, Larry Silver, Ed Snell
Communication and Assistive Technology Department
Bloorview Children's Hospital
Willowdale, Ontario. CANADA

ABSTRACT

For individuals with progressive degenerative disorders technology reduces the effect of disability on active and vital lifestyles. As more and more pieces of technology are added to an individual's system it is important that an overall perspective of the client, their needs, and their existing technology be considered. A smooth integration of new and existing technology can increase the functionally and potential of the entire system. This paper describes the prescription and integration of a computer access system with powered mobility, powered tilt system, portable ventilator, and environmental control.

BACKGROUND

John is twenty four years old, has a diagnosis of Duchehenne's Muscular Dystrophy and has required full time ventilation for the past six years. He uses powered mobility, has interests in vocational pursuits and enjoys recreational reading. Formally an inpatient of Bloorview Children's Hospital, John is currently living in an apartment supported by attendant care services and assistive devices.

The powered mobility system is based upon an Invacare Arrow with an MCC MK III controller and 1551 switch option interface. The Roho seating is incorporated into a TARSYS tilt-in-space system with a QUAX interface. The QUAX allows the use of a single input switch to alternately control UP and DOWN movement of the tilt-in-space system. The tilt-in-space system provides independent pressure relief controlled through a low force (.98 Newtons) microswitch accessed by John's right thumb. Careful consideration was given to mounting a portable ventilator (1)(2) on the powered wheelchair. The mobility system was supplied in 1993.

Dual modes of control for the powered mobility system were provided through a short throw joystick and a sip and puff interface. Originally the sip and puff interface was intended to be used when fatigue and cold temperatures prevented use of the short throw joystick. Latched sip and puff, adjusted for the most sensitive pneumatic levels, has now become the exclusive access method for mobility. A second low force microswitch (mounted adjacent to the tilt-in-space microswitch and also accessed by the right thumb) was provided to select modes on the MCC controller. These modes are STANDBY, DRIVE A, DRIVE B, SPEED 1, SPEED 2, SPEED 3, and ECU 1 and are stepped through sequentially with each activation of the microswitch. DRIVE A and DRIVE B were setup to represent short throw joystick and sip and puff control schemes respectively.

ECU 1 on the MCC controller provides four dry contact relay outputs with a common ground. Each of the relay outputs can be selected by respective activations of the mobility interface's FWD, REV, LEFT and RIGHT directions. Two of the outputs were used to control a two channel Stanley door transmitter which John used to open his apartment door and apartment building front door. The other two outputs were used to control the Bloorview Wireless Switch Link transmitter. The Bloorview Wireless Switch link is a dual channel, radio frequency, transmitter/receiver set which provides wireless switch access to stationary equipment. In John's case, this accessed the CHEC 2 (3) integrated environmental control system and allowed him to control his home entertainment equipment, telephone and other devices involved in daily living. A Bloorview Battery Adaptor (4) converts the 24 volt wheelchair batteries into three independently adjustable voltages. Two of these voltages powers the Stanley door transmitter and the Wireless Switch Link to eliminate the need for disposable batteries.

For written communication John had used a series adaptive devices that changed as his needs increased and his physical abilities declined. His first computer, an IBM AT was initially accessed through the keyboard and a hand held pencil. As range of movement and fatigue became a problem, the Bloorview Mini-keyboard (5) was developed for John. This was a small, 7" x 2 1/2", keyboard based on the Sharp PC-1360 Pocket Computer, requiring only 30 grams of force to activate the keys. John acquired a donated Amiga computer in 1989 for graphics and game use. His functional range of movement and available strength had decreased to the point however where the Mini-keyboard no longer could meet his needs. The technologist and programmer at Bloorview Children's hospital adapted the Amiga to accept two switch mouse cursor control and Morse code character input. John continued to use this computer until his move to an attendant care apartment two years ago.

John's mobility and environmental control systems continue to "evolve" with his changing needs. Most recently his needs have been directed towards desk top publishing as a vocational goal and the tools necessary for this achievement. John requested the Writing Aid Clinic at Bloorview Children's Hospital to review his personal writing aid needs.

ASSESSMENT

There was the presence of bilateral elbow flexion contractures in the left arm of 105 degrees and right arm of 90 degrees. Wrist flexion contactures were also present with a left wrist flexion contracture of 105 degrees and right wrist of 95 degrees which restricted functional hand use. Bilateral arm troughs had been provided to stabilize the elbows and forearms. Any movement against gravity was difficult for John.

It was decided to try a Macintosh based system with John. A wide range of commercial software specific to John's educational and career goals was available for the Macintosh. Several options for the alternate access required by John were also available. Ke:nx operating as the single switch Morse input device was chosen as the alternate access method because of John's pervious experience with Morse code. A TASH mouse emulator to provide on screen cursor control through John's wheelchair ECU output was obtained, and the system assembled for trials.

John had functional use of both his right thumb and his left little finger, being able to exert forces of .49 and .61 Newtons respectively. The right thumb was already operating his wheelchair seating tilt system and his wheelchair controller mode select functions through two low force microswitches. A third low force microswitch was placed beside and anterior to the first and second switches. This was however at the extreme functional range of John's right-hand thumb. Fatigue would quickly set in given the thumb extension required to reach the switch and the high number of separate activations needed to input Morse. John's left hand and specifically his left little finger, was now free for other functions with the recent switch to sip and puff for wheelchair control. The available force of .61 Newtons was enough to operate a low torque microswitch. It was anticipated however that fatigue would still be a problem given the number of activations needed to generate Morse code. A capacitive touch switch, which has the characteristics of zero travel to activate and near zero contact force (6), was chosen as the Morse input switch to help minimize fatigue. The capacitive touch switch plugged directly into the Ke:nx hardware box and the Ke:nx Morse code software setup was loaded as the Macintosh power on configuration.

The second ECU output of the Arrow wheelchair controller was enabled. A custom 9 pin cable was constructed to connect the ECU 2 outputs to the TASH Mouse Emulator providing John mouse cursor movement control through his wheelchair sip and puff control system. The "Mouse Select" was activated by the third microswitch accessed by John's right thumb and its output tied into the 9 pin cable.

Sip and puff control of the mouse proved to be a problem during training. John experienced difficulty in maintaining the "hard" puff needed to move the mouse's cursor up screen. There was also the combined effect of using the wheelchair sip and puff control with the TASH mouse emulator, a combination which produced on screen mouse movements too coarse for easy control. Intended targets were overshot and considerable cursor repositioning was required.

At this point it was decided to try the Bloorview Mini Morse (7) for mouse emulation through the touch switch inputting of Morse code control sequences (7). This would be a less direct method of mouse cursor control than using the directional ECU 2 outputs. It did prove to provide better control of the cursor due to the Mini Morse's ramped speed mouse cursor movement.

Morse input to Ke:nx had also proved to be a problem as the Morse code speed adjustment was not fine enough to meet John's needs. The Mini Morse was also be able to emulate the Macintosh keyboard directly from the Morse coded character input stream (from the capacitive touch switch). The Mini Morse was able to replace the Ke:nx hardware/software as well as the TASH mouse emulator. The microswitch remained as the mouse select.

It became apparent that the cables required between John's wheelchair and the computer system would become a problem. First, they required another person to connect them each time John wished to use his computer. Second, there would be long term durability issues as these cables were connected and re-connected. It was John who came up with the unconventional solution to these problems. This solution was to use his Infrared Remote Control Pad System for his SEGA game system as the wireless link from his wheelchair to the computer and Mini Morse.

This would require adaptations to both the transmitter and receiver of the Infrared Remote Control Pad System. The transmitter would be mounted on the wheelchair, powered from the wheelchair through the Bloorview Battery Adapter, which was already powering the Wireless Switch Link and Stanley door transmitters. The direction control pad was tapped into and a connector provided to connect it to the wheelchair controller's four ECU 2 outputs. The Sega "Fire" control buttons B and C were also accessed by the third right-hand microswitch (acting as mouse select) and the left-hand little finger capacitive touch switch (morse code character output).

The receiver normally obtained power from the SEGA Control Deck which would not be present when used with the computer. It was necessary to provide it with an external AC adaptor and DC voltage conversion circuitry. Connectors were added to the Sega receiver to take the "Fire B", "Fire C" and FWD direction control pad signal and convert them into three single switch outputs. These plugged directly into the Mini Morse.

John's Mini Morse meanwhile had been modified by Bloorview's software programmer to accept input from three switches. Input from switch 1 would be decoded as Morse code character input. A switch closure through switch input 2 would initiate a scanned mouse movement (7). Switch input 3 would act as mouse select button.

This combination of Macintosh and Mini Morse, with capacitive touch switch, microswitch and sip and puff controlled ECU output, linked by the SEGA remote game pad, proved to be the optimal system for John.

RESULTS

John came to the clinic an experienced technology user with some fairly specific ideas on what he would like from a writing aid system and how he would like to access that system. He was an important and integral part of the assessment and prescription process providing insights into the wheelchair/ECU technology that he already used. His ideas for blending and customizing his new writing aid system, with other available commercial technology were invaluable. The system incorporated many parts of John's existing technology, integrating old and new into one overall system. John now has this system at home, providing him with independent access to a writing aid which will help him meet his future academic goals.

REFERENCES

1.Gilgoff, I., Montes, L. A. "Breathing Easier, Beyond Mechanical Ventilation for Neuromuscular Patients"*Team Rehab Report* , October 1992, pp.15-16.

2. Sukstorf Laurence, S. "Integrating Ventilators with Powered Mobility" *Team Rehab Report* , October 1992, pp.17-19.

3. Snell, E., Silver, L., Ridpath, C. "The CHEC 2, Integrated Environmental Control System." In *Proceedings of the RESNA 15th Annual Conference*, Toronto, Canada, June 17-22, 1994, pp.561-563.

4. Snell, E., Silver, L. "Extending the Functional Day for Powered Wheelchair based Technologies. " In *Proceedings of the RESNA 17th Annual Conference*, Nashville, Tennessee, June 17-22, 1994, pp.103-105.

5. Poss, J., Whyte, N., Ridpath, C. "The Application of a Pocket Computer as a Keyboard Emulator for Individuals with Degenerative Muscular Conditions" In *Proceedings of the RESNA 9th Annual Conference*, Montreal, Canada, June 25-30, 1988, pp.412-413.

6.Snell, E. "Capacitive Touchplate Controller for Powered Mobility in Severe Motor Disability", *Digest of the 4th Annual Conference on Rehabilitation Engineering*, Washington, D.C., August 30 - September 4th, 1981, pp.69-71.

7.Ridpath, C., Snell, E., Silver, L., "MiniMorse - Morse Code and Mini-keyboard Access to Popular Computers", *Proceedings of the CSUN Conference*, Los Angeles, California, March 1994.

Bert Shire
Bloorview Children's Hospital
25 Buchan Court
Willowdale, Ontario, M2J 4S9.
CANADA
(416) 494-2222

THE COST X PERFORMANCE TRADEOFF FOR VOICE OUTPUT AAC AIDS: IS IT REAL?

J. M. Martins Ferreira, M. Gradim Gericota, M. Lourdes Lourenço
INESC / University of Porto and Cerebral Palsy Rehabilitation Center
Pr. da República, 93 - 4000 Porto - PORTUGAL

ABSTRACT

The cost of voice output AAC aids is still too high, which prevents many persons with speech impairments to benefit from this technology. However, advances in speech coding techniques and in microelectronics (integrated circuit complexity, and packaging and mounting technology), have enabled new solutions which will in the short future provide a generalized access to voice output AAC aids. This paper presents the basic issues dealing with the technology of voice-output communication aids, describes two new types of solutions based on very low-cost technology and highlights the implications which can be brought to the AAC field itself if a truly generalized access to high-complexity and low-cost voice output devices effectively becomes real.

BACKGROUND

Augmentative and Alternative Communication (AAC) may be defined as "an area of clinical practice that attempts to compensate (temporarily or permanently) for the impairment and disability patterns of individuals with severe expressive communication disorders (i.e., the severely speech-language and writing impaired)" [1].

Both graphical and gestural mode communication systems are extensively used in AAC. Graphical mode systems include such alternatives as PCS (Picture Communication Symbols), PIC (Pictogram Ideogram Communication), Blissymbols, etc., and can be used either with direct selection or scanning techniques. While non-electronic methods for displaying symbols (e.g. communication boards) are basically inexpensive, electronic methods present several advantages. Beside making it much easier for the listener to follow a conversation, electronic communication aids with voice output allow the user to express him/herself even if the listeners are not momentarily paying attention.

Voice output AAC aids can be used with any the previously referred communication systems, although other alternatives are also available. The Minspeak^{TM} system [2] is a good example of a powerful language representation system which would be much less appealing if it didn't have voice output. Both synthesized (where each word is generated by concatenating basic phonemes) and digitized voice output are possible. While the former is usually employed in more powerful systems (where the number of sentences which can be reproduced is not limited), the latter usually produces better quality speech (words or sentences are digitized and stored in digitized form).

Voice output AAC aids make extensive use of speech coding technology, which deals with the compact representation of voice signals for the purpose of efficient transmission or storage [3]. Very substantial progress was made in this area during the past decade, the main reason being its importance for civilian and military communications and for computer related voice applications. Research in this area became very active during World War II due to its strategic importance for encrypted speech communication. Many advanced algorithms for efficient speech coding are now practical due to developments in microelectronics technology, which presently enables the production of ICs (integrated circuits) with more than 4 million transistors.

The importance of speech coding for many areas of the consumer electronics market is responsible for the availability of very sophisticated multi-purpose components and sub-systems, which can also be used to the advantage of people with speech impairments. Among other possibilities, ADPCM (Adaptive Differential Pulse Code Modulation) is one technology for which many dedicated ICs and even pre-assembled modules are now inexpensive and available on the market. The basic idea behind ADPCM consists of sampling the analog speech signal and converting it to digital form, but storing only the difference between the amplitudes of the present and the previous samples. The step size and the correlation factor with previous samples are allowed to adapt to the time-varying statistic properties of the speech signal.

When each analog speech sample is taken with a 12-bit resolution (differentiating among $2^{12}=4096$ discrete values), the difference between adjacent samples can be stored using only 4 bits per sample (reducing the required memory to one third, when compared to the full binary representation).

Although digitally coded speech allows transmission rates well within the available bandwidths and provides better noise immunity for communication over long distances, the compression ratios achievable are not yet entirely satisfactory for storage purposes. ADPCM provides good quality speech transmission at 32 kbps (kilobits per second), but if its digital representation has to be stored, approximately 1 Mbyte of memory is required for 30 seconds of speech.

An alternative technique, which emerged in the last 3 to 4 years, uses standard digital memory cells to directly store and read information in analog form [4]. DAST™ (Direct Analog Storage Technology) significantly improves the storage efficiency when compared to digital coding methods (achieving a 4:1 storage advantage over ADPCM) and is therefore a serious low-cost competitor to ADPCM for many voice record and playback systems.

STATEMENT OF THE PROBLEM

Since speech coding is now a mature technology, it is somehow surprising why a generalized access to voice output AAC aids is not yet possible, specially because one major reason for this fact is that cost is still too high for many potential users. This is indeed the main problem presently restricting access to voice output AAC aids at the Cerebral Palsy Rehabilitation Center of Porto, where a much larger number of persons with speech impairments would like to use this technology.

The aim of the work described in this paper was therefore to use very low-cost technology to develop good quality voice output AAC aids, adaptable to the dynamic requirements of AAC interventions in children and young adults with cerebral palsy.

APPROACH

Following an user requirements identification phase where the main functional and interface issues were agreed, several alternative technologies were considered as possible candidates. It must be said that most of the technologies which were considered were generally able to meet the cost and performance requirements. A first prototype was developed which used a commercially available dedicated ADPCM chip to provide a portable communication device able to store up to 100 messages [5]. The feedback obtained from the users testing this prototype was very positive and it is now in the process of being industrialized. Two additional types of solutions were meanwhile developed, which are described in the following paragraphs.

One of these solutions consists of small and very low-cost prototypes meant to stimulate early communication and language capability acquisition in children with cerebral palsy. This prototype was based on DAST™ technology and is illustrated in figure 1.

Fig. 1: A voice output device for children with CP.

Up to 16 seconds of speech can be stored in this device (speech recording is done by speaking to the microphone shown in figure 1, while the record button is pressed) and the quality of the voice output is perfectly acceptable[1].

The second type of solution is illustrated in figure 2 and consists of more sophisticated devices, where up to 254 messages can be made available and several operating modes selected. Again, recording can be done directly with a built-in microphone, which is common to many of the communication systems already commercially available.

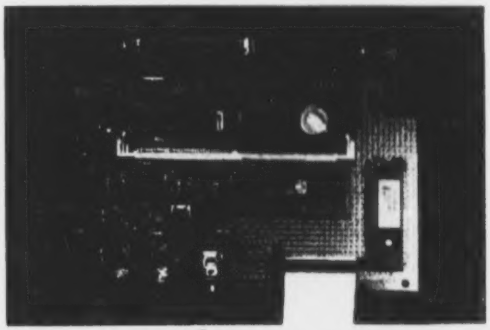


Fig. 2: A DS2271[2]-based voice output device.

---

[1] In technical terms, the device specifications guarantee a signal-to-noise ratio of 40 dB, a 3-dB bandwidth of 3,4 Khz and a total harmonic distortion of 2% at 1 KHz.

[2] The DS2271 is a multi-purpose speech stick marketed by Dallas Semiconductor.

152

The main innovation in this prototype is in fact its much lower cost, when compared to the products available on the market, which was made possible by the use of a multi-purpose solution integrating all the required electronics in a very compact module [6]. Several user interface alternatives and operating modes have been implemented. Voice output can follow each selection, but a complete sentence can also be defined before the corresponding phrase is output. Dynamic memory management ensures that all the existing memory can be used even when the words or sentences have different lengths (when a message is to be modified, it is first deleted, then all the following messages are shifted back to fill the hole left by the message removed and only then the new message is stored).

IMPLICATIONS

Within the limited scope of the Cerebral Palsy Rehabilitation Center of Porto, the very low-cost of the range of solutions which were developed in the course of this project met the objective of enabling a generalized access to voice output AAC aids. An immediate implication of this result is that the speech therapists working at this institution are now introducing more sophisticated AAC aids at a much earlier stage, both for children and for young adults. At the same time, a specific program has started to assess the improvement in communication and language acquisition capability, when compared to the use of non-electronic AAC aids.

The identification of additional applications where voice record and playback devices might be of interest to people with speech impairments, specially if very low-cost allows a non-restricted number of devices to be used anywhere, has also started to be considered. Although the evaluation work has so far been related to the specific requirements of people with cerebral palsy, aphasia is an area which will soon be considered as well.

DISCUSSION

The results obtained clearly indicate that speech coding and microelectronics technologies have matured enough so that very sophisticated building blocks are now widely available at inexpensive prices. One major consequence of this fact is that there is really no reason to compromise quality to cost, since the latter is basically dependent on other factors than the cost of the components or sub-systems used in many voice output AAC aids.

On the other hand, it is highly probable that voice output will start to be combined with voice recognition in a larger number of application areas, such as hand-held personal digital assistants, digital answering machines and a variety of voice organizers, such as memos, calendars and to-do lists [7]. The general trend in this field is therefore that cost will continue to decrease while product performance will continue to increase, mainly because additional application areas in the consumer electronics mass market will start to become practical as technology evolves.

REFERENCES

[1] D. Beukelman, P. Mirenda, *Augmentative and Alternative Communication*, Paul H. Brookes Publishing Co. Inc., 1992 (AAC definition according to the American Speech-Language-Hearing Association — ASHA).

[2] G. Van Tatenhove, *What is Minspeak^{TM}?*, Prentke Romich Company, 1993.

[3] A. Spanias, "Speech Coding: A Tutorial Review," in *Proc. of the IEEE*, Vol. 82, n° 10, pp. 1541-1582, October 1994.

[4] F. Goodenough, "IC Holds 16 Seconds of Audio Without Power," in *Electronic Design*, January 31, 1991.

[5] J. M. Ferreira, A. Teixeira, J. Ramalho, M. Lourenço, "A Portable Device to Improve the Communication Ability of People with Cerebral Palsy," in *Proc. of the 6th ISAAC Conference*, Maastricht, NL, pp. 446-448, October 1994.

[6] DS2271 Speech Stick Data Sheet, Dallas Semiconductor Teleservicing Design Handbook, pp. 212-232, July 1991.

[7] J. Gallant, "Speech synthesis and recognition chips personalize consumer products," in *EDN Europe*, pp. 51-57, October 20, 1994.

ACKNOWLEDGEMENTS

This work was partially supported by the Secretariado Nacional de Reabilitação through an HORIZON project entitled "Implementação de um Laboratório de Informática e de Electrónica".

José Manuel Martins Ferreira
INESC / University of Porto
Pr. República, 93 - 4000 Porto - PORTUGAL
Tel. 351-2-2094242 - Fax: 351-2-2084172
E-mail: jmmf@inescn.pt

COMMUNICATION EFFECTIVENESS IN RECREATION ACTIVITIES BY AUGMENTATIVE COMMUNICATION USERS IN BRITISH COLUMBIA

Beth Thompson, M.Sc., S-LP(C) and Danielle Tessier, M.Sc., S-LP(C)
Sunny Hill Health Centre for Children and B.C. Rehabilitation Society-G.F.Strong Centre
Vancouver, B.C., Canada

ABSTRACT

Many adolescent and young adult augmentative and alternative communication (AAC) Users in the province of British Columbia are making the transition from secondary school settings to post secondary and work experience situations. They have had the benefit of fully inclusive school settings, which offered a structure for their activity and program choices. Consequently, they have the expectation that they will be successfully integrated into all community activities as equal partners. Unfortunately, the use of their AAC systems may impede their inclusion, as the greater public may not have the skills to facilitate their conversational interactions, and the AAC Users may not be perceived as competent communicators. They may not independently choose recreation activities, and may not have the skills and to access and participate independently in public recreation activities. Our programs are surveying adolescent and young adult AAC Users to identify what recreation activities they would like to attend and what vocabulary and interaction skills would make them more functional as independent communicators.

BACKGROUND

Recreation is defined as "any activity pursued during leisure, either individual or collective, that is free and pleasureful, having its own appeal, not impeded by a delayed reward beyond itself or by immediate necessity" (4). People, therefore, participate in recreation opportunities to relax, exercise, socialize, and to learn new skills.

Young people with disabilities are now participating in many public recreation activities in the community, as equal partners to their same-age peers. These young people have had the advantage of experiencing inclusive education opportunities and have learned to adapt their needs and equipment for familiar and unfamiliar environments (5).

Unfortunately, it has been more difficult for young people who do not use intelligible speech as their primary communication system (nonspeaking or nonverbal), to make the transition to recreation activities in the community (5). They may have limited available vocabulary or messages on their AAC systems, restricted practise in unfamiliar environments, and/or unfamiliar communication partners that cannot support or facilitate their conversational interactions. It may be assumed that these young people would not benefit from participating in some public recreation activities as they can not successfully communicate their needs, and therefore some activities may not be made available. For this reason, these adolescent and young adult AAC Users may choose to not try new recreation opportunities, or may become observers, or passive participants, depending on partners for assistance and support.

As noted in the literature, many adolescents with disabilities are isolated, both because they experience rejection from peers and because they have a decreased number of opportunities for participation in activities with friends, family, and community members. They report that they experience a longer or extended adolescence (2) and have less confidence in developing adult skills for independence and direction in planning and scheduling time, particularly when structure is not provided. They may not have effective strategies to learn independence in selected activities, and may depend on others to mediate new settings and partners. It is also clear that we cannot assume that we know which recreation activities will be chosen by these adolescent and young adult AAC Users, and that we can not be bound by stereotypes, or self-imposed barriers (5).

Our clients in Vancouver and the province of British Columbia, reflect a growing trend of young people with severe communication difficulties, who are active and included in secondary schools, and beginning the transition to post secondary and work experiences. They have been fully integrated in their school placements, and many of their expectations are to become full participants in their local communities. We have noted an increasing number of these young adolescent and young adult AAC Users report problems with accessing community recreation. This may be because of restricted ability to register and make their needs known to unfamiliar activity leaders, or restricted or inappropriate messages and interaction skills for unfamiliar partners.

These difficulties are particularly reflected in their dependency on having others choose activities for them, plan schedules, introduce them, and act as intermediary for giving and receiving information. They may have let the nature of their disability limit the number of recreation activities they have tried, and therefore may have compromised their self determination in choosing and participating in recreation activities.

Our challenge, as team members working with young AAC Users, preparing for the transition from a secondary school environment, has been to recognize that they need access to not only vocabulary and interaction skills appropriate within the school environment, but also strategies on how to relax and recreate, and consequently socialize in their greater communities. Our intervention must move from structuring expectations for their AAC systems and interactive opportunities, and shift to preparing them to make communication decisions that will lead to their satisfaction as independent participants. Ultimately, community recreation leaders also have a responsibility to learn techniques to more effectively facilitate interactions with non-speaking young adolescent and young adult AAC Users (8), so that they can have more choices of activities, and input in how they wish to participate.

RESEARCH QUESTIONS

1. What recreation activities are adolescent and young adult AAC Users presently attending, and how often do they attend?
2. Do they think their AAC systems are adequate for the activities and are they able to actively participate and communicate with their partners?
3. Are there recreation activities that they wish they could attend or learn more about, and what would they need to change on their communication systems to make their participation possible?
4. Are there general vocabulary and messages strategies/interaction and conversational skills needed by young adult AAC Users so that they can be more effective communicators in pubic recreation activities?
5. What skills could recreation leaders acquire so they could more successfully include people with severe communication disabilities as active participants in their programs?

METHODS

Subjects

We have identified 20 adolescent and young adult AAC Users, between the ages of 16 and 24 years living in British Columbia. They demonstrate a range of disabilities, which impair both motor and communication function. All of these young people rely on augmentative communication systems for their primary interactions, and may use them in combination with vocalizations, word approximations, gestures, facial expressions, and yes/no responses to communicate. Their AAC systems may be nontechnical (symbols, letters) or technical (voice output computers), and/or a combination of both. They have developed enough competence as communicators so that unfamiliar communication partners (a trained interviewer) can interpret their communicative intent. AAC systems may be accessed directly (pointing, eyegaze) or indirectly (scanning). All of the identified AAC Users have received services from one or both of our agencies.

This survey will be conducted by a trained interviewer, who will be familiar with facilitating communication interactions with AAC Users. The adolescent and young adults will be accompanied by familiar communication partners, if they wish. Questions on the survey will be asked verbally and reinforced using a black and white picture of the activity. A short explanation of the activity will be given if the AAC User doesn't know what the activity is, or if more information is requested. Fifteen items will be chosen randomly and presented during the interview. AAC Users will be asked if they are presently participating in the identified activity, do they wish they could attend, what communication skills would assist them to participate, and would it assist them to have a trained communication partner. Accepted responses for each question will be yes/no, and the AAC User will be able to choose which communication system they want to use to respond.

RESULTS

We are in the initial stage of this project, and are in the process of surveying adolescents and young adult AAC Users on their choices of recreation activities. We will complete the initial survey by April 1995

Responses from our survey, when it is completed, will be reflected in the next stage of our project. We anticipate that our respondents will identify a number of recreation public recreation activities that they would like to participate in, and also provide us with information on how to develop their communication skills so that they can be more actively included as equal partners in the activity. We expect that they will also give us initial information on whether they require trained communication partners to participate, and what skills partners need to develop to be effective facilitators.

DISCUSSION

An outcome of inclusion in regular school settings has been the development of expectations for full accessibility and integration for all young people with disabilities in our community. This integration moves beyond accessible washrooms and designated parking, and extends into equal opportunities for public recreation choices, and active participation as an effective communicators, with choices for partners and friends. It is critical that we serve our young adolescent and young adult AAC Users by providing them with communication systems that are functional for school use. We must also take the time to teach them interaction and communication skills that will assist them to gain independence and success in the community throughout their transitions to other life experiences.

The first stage of our survey will be completed and collated by May 1995, and we will share our initial survey impressions, and will discuss results as reported by the adolescent and young adult AAC Users. This will include information on what they choose for recreation activities, what communication and vocabulary messages they would like to have available, what interaction skills they need to develop, and how they would like to communicate their needs within a recreation setting. We will discuss implications for the next stage of our project, including program suggestions for assisting recreation leaders to develop skills for being a communication partners, and suggestions for easing the transition of adolescent and young AAC Users from structured school environments to independence and success in the community.

REFERENCES

Blackstone, Sarah W. (1993). What do you want to be when you grow up? ACN. 6:4,1-5.

2 Blackstone, Sarah W. (1993). Adolescence: Reflections of AAC Users. Augmentative Communication News (ACN). 6:3, 1-3.

3 Diamanti, T. (1989). Adolescent Servicing. Communicating Together. 7:3, 1

4 Dictionary of Sociology, New York: Philosophical Library, 1944, 25.

5 Jenkins, Christopher J. (1993). Adolescence and Transition for Individuals with Physical Disabilities: A review of the literature. Unpublished.

6 Light, J. (1989). Towards a definition of communicative competence for individuals using augmentative and alternative communication systems. (AAC). 5:137-144.

7 Strully, J. and Strully, C. (1985). Friendship and our Children. The Association for Persons with Severe Handicaps. 10:4, 224-227.

8 Verburg, G. (1989). Learning to be Independent. Communicating Together. 7:2, 9-10.

ACKNOWLEDGEMENTS

Our thanks to Dr. Maureen O'Donnell, Medical Director of the Neuromotor Program, for her valuable contributions to the research and development of this survey.

Beth Thompson, M.Sc., S-LP
Registered Speech Language Pathologist
Neuromotor Program
Sunny Hill Health Centre for Children
3644 Slocan Street
Vancouver, BC
V5M 3E8
Telephone: (604)436-6514
Fax: (604) 436-1743
Email: betht@sunny wimsey. com

THE AMOUNT OF INFORMATION TRANSMITTED BY THE RESIDUAL FUNCTIONS IN MOTOR-DISABLED PERSON

Toshiyasu Yamamoto*, Junichi Ohshima*, Tetuya Yamashina*, Masafumi Ide**

*Toyama Prefectural Koshi Rehab Hosp, **Spinal Injuries Center, Labor Walfare Corporation

ABSTRACT

This study is mainly concerned about quantitative assessment of interface control of the input/output devices for the motor-disabled person. The amount of information is preliminarily discussed from a viewpoint of information theory, which are defined by multiple access channel, information density, and capacity. Also kinematic analysis of the upper extremity has been preliminarily introduced to to explain a relation between the compensatory movements and the pointing errors in the reciprocal and discrete pointing. It may be useful to estimate a better interface system with the brain

INTRODUCTION

In the field of medical and occupational rehabilition, to enhance the work capacity at workplace, and at home, it is necessary to estimate the task performance ability, suitable for operating and manipulating the devices.

The object of this study is to discuss with a method to assess the amount of information of redisual function, and make fit with the amount of information of operating the devices.

As a measure to express the fitness for the interface system of command control, the following two kinds of indices are introduced, analogous to information theory; (1) multiple access channel (channels), (2) information density (bits/sec), (3) information capacity(bits).

Multiple access channel is defined as the number of information access, used for command control. Information density was introduced by Fitts(1954). The amount of information of human motor system is discribed as the variables of analog measure of successive responses. It is infered as the mean information transmission rate.

In 1980, Sakkits defined information capacity as the resolution of angular motion of the joint. This attractive approach has been also applied widely, because it can be explained with no connection with difference in the physical measures.

In this preliminary study, we have eximined the usefulness of information theory approach to estimate the human performance in reciprocally and discretely pointing a target. This approach may be able to use a new measure of assessment of the residual functions for a better communication interface system with the barin.

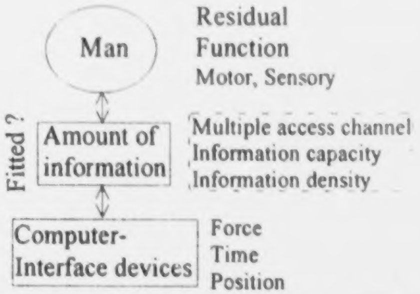


Fig. 1 Fitness of the amount of information for the interface system to manipulate the electronic devices.

EXPERIMENTAL SET UP

The measurement system is composed of 1) 3 dimensional electromagnetic positoin sensor (EMPS, 3 SPACE ISOTRACK, POLHEMUS) to sense the motionof the upper extremity , and 2) color LCD (14inch) with touch position sensor (TPS).

4 sensors of EMPS has been fitted on acromion, distal and post. region of humerus, ext. retinaculum, and dorsum manus. The pointing coordinates are

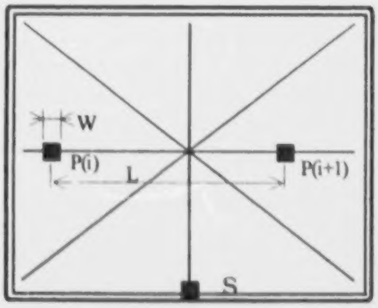


Fig. 2 2 dimensional setup of experimental display for reciprocal and discrete motion

S = starting point, P(i) = pointing target, W = target width, L = movement distance between 2 targets

In reciprocal pointing, after holdind the hand, the experiment starts on pointing S. P1 and P2 are shown on the display during a session. In discrete movement, for each trial, after folding the hand, the subject points a target after appearing for 0.5 sec (regulated with the level of motor impairment: 0.5~2.0 sec) on the 8 directions of randamized position

INFORMATION OF THE RESIDUAL FUNCTIONS

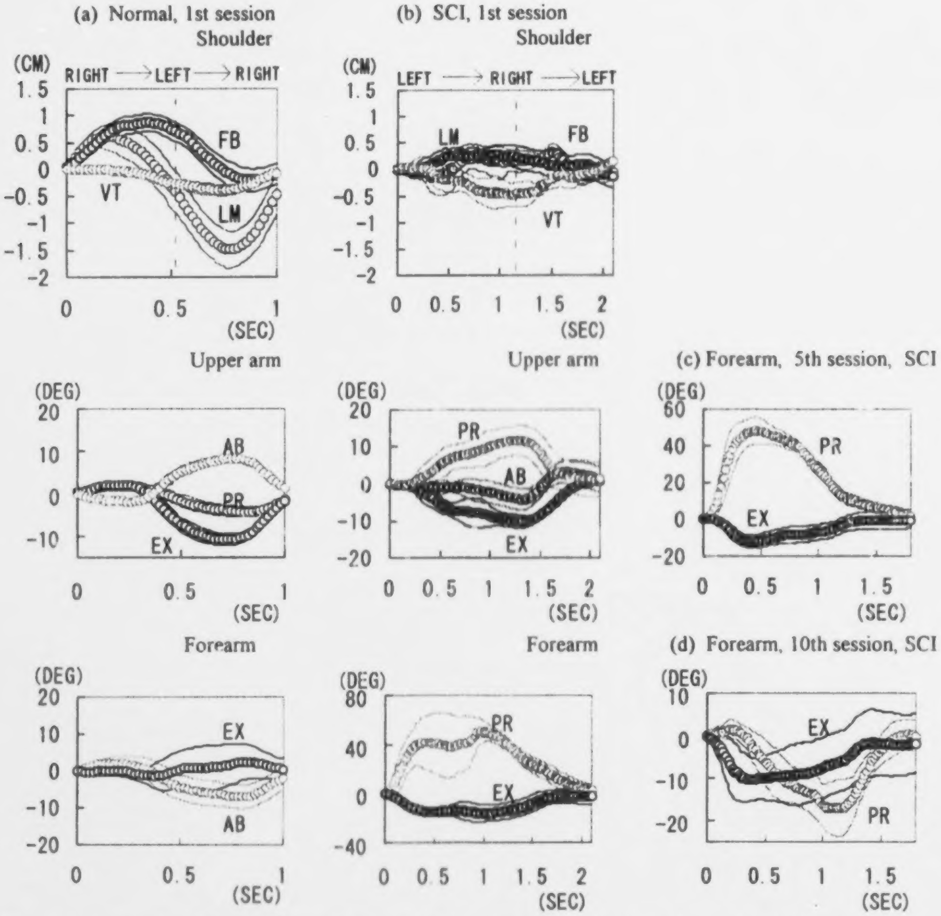


Fig. 3 An example of the motion patterns of the upper extremity in reciprocal pointing
The normal and SCI subject put long oponens wrist hand orthosis to lock the wrist joint. Movement distance = 16cm, target width = 1.0cm□, # of sessions = 10, # of reciprocal motion for each session = 25 for the normal, 10 for the SCI patient. Each pattern is shown in the curves of the mean ± s. d., FB = forward/backward, LM=lateral/medial, VT=vertical displacement, PR=pronation(+)/spination, AD=abduction/adduction(+), EX=extension(+)/flexion direction

directly picked up by the touch positoin sensor .

The movements used are reciprocal and discrete pointing. In reciprocal pointing, The experimental technique is almost the same as Fitts. Here it is extended into such a 2 dimensional surface as CRT display. In discrete pointing, as an example of the horizontal direction, the total distance 24.5 cm is divided in 49 sections. W = 0.5, 1.0, 2.0 cm□, and L = 16, 8, 4 cm. The subject was indicated to point a target as fast and accurate as possible, and not to adjust pointing at the end of target. The subjects are 14; normal = 6, SCI = 4, CP = 4.

KINEMATICS OF THE UPPER EXTREMITY

Here only the results of normal and SCI subjects are shown. There are few of kinematic motion analysis of the upper extremity, especially on the joint movement of pronation /supination.

The normal shows a smooth coordinated motin pattern with the smaller varialbes (s.d.). He mainly controls a motion round the shoulder, and may adjust the joint angles for a precise pointing.

The SCI patient is C5 paralysis. His left hand is of a weak flexor, pronator/spinator (PR/SP) of the forearm, which moves with lighter load. The right hand is motor-impaired severely .

His shoulder scarecely gained movement because of difficulty in trunk control. The upper arm has a similar motion as the normal, but a longer and delayed motion in the vicinity of reciprocal pointing. He usually has a large PR/SP of the elbow joint, which has a faster response at the beginning of a pointing motion. This compensatory movement may be related to set a direction, together with extension /flexion of the elbow joint.

Lastly we point out that the forearm movement is irregular because of weak muscle force, frequent muscle fatigue, and limited range of motion (ROM), though the variables of the velocity of the hand become larger by adding another session. It may lead to the larger pointing errors

MOVEMENT TIME AND POINTING ERROR

Here we tested how compensatory movement affects the pointing accuracy at the end of the arm. The distribution area of pointing (DA) is calculated by estimating the eliptic area, on 2 dimensional normal distribution hypothesis (95% c.i.). A typical movement time (MT) and DA are shown.

In the normal, DA area is less than 1cm□, and MT is not well-correlated with the movement distance (L). In the CP, (quadriplegia, with athetosis), MT has a tendency to decrease with smaller L, but has comparatively larger variances. DA is not correlated with L, and has difference in pointing between the right and left targets, because of difficulty in trunk positioning control. Next, SCI has a remarkable tendency in dependence on a limitted ROM, that is, a large difference of DA between the right and left targets, and a shorter MT with a smaller L.

These chracteristics of MT and DA are very useful to estimate one of the main parameters for the responses of motion control at the end point.

INFORMATION ON POINT RESOLUTION

It is useful to test the point resolution for quantitative digital measure of the residual function. Here a discrete pointing is used, and its setting is described before. A technique to calculate transmitted information (TI) can be referred to a original paper of Sakkits.

In Fig. 5, an example of the experimental results is shown. In the normal, TI is 4, with the eyes open, and 3 bits with the eyes closed. This subject of CP has a similar accuracy with the normal with the closed. In the case of SCI, it was a little better than CP. These results shows that it is possible for the direct pointing motion to apply for Sakkits' method.

For the future work, it may be made use of clarifying the cognitive spatial-motor process in comparison with data obtained under different behabioral manipulation.

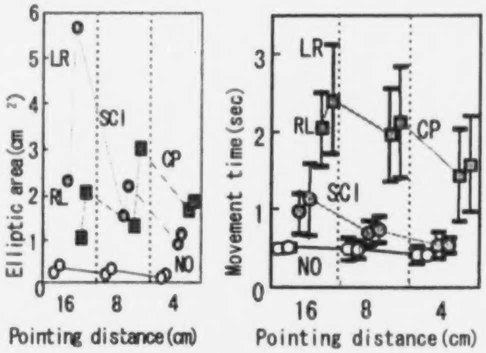


Fig. 4 Movement time and the pointing errors
RL = from right to left, LR = from left to right, in reciprocal pointing. NO, SCI, CP = an typical subject of the normal, and SCI, and CP

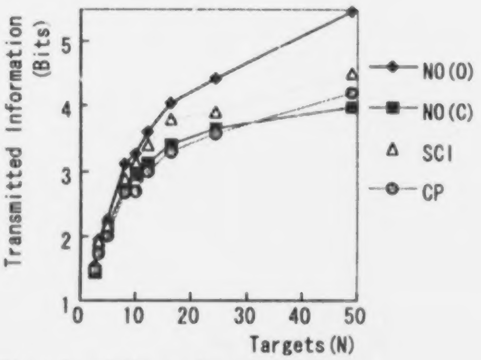


Fig. 5 Resolution in discrete pointing
O, C = with the eyes open, and closed

REFERENCES

1)Fitts, P. M.: The information capacity of the human motor system in controlling the amplitude of movement, J. Exp Psychol, 47, 381-391, 1954
2)Sakkits, B., etal: The information transmitted at final position in visually triggered forearm movements, Biol Cybern, 46, 111-119, 1983
3)T. Yamamoto, Measurement system to assess input control of computer for difficulty in upper extremity, Proc. of 16th Anuual International Conference, IEEE EMBS, Baltimore, 1994

ACKNOWLEDGEMENT

A part of funding for this study is provided by Japan Foundation for Aging and Health, supproted by the Ministry of Health and Walfare.

Toshiyasu Yamamoto
Rehab R&D Dept, Toyama Prefectural Koshi Rehab Hosp, 36 Shimo-lino, Toyama 931 JAPAN
Tel:(0764)38-2233, Fax:(0764)37-5390

ASSESSING PICTURE-RELATED SKILLS USING LASCAUX

Beth Mineo, Denise Peischl, Patrick Demasco, John Gray, Rachel Bender
Applied Science and Engineering Laboratories
University of Delaware/A.I. duPont Institute

Abstract

This paper provides evaluative data from the implementation of an assessment application developed with Lascaux that targets picture-matching skills. Even though picture-matching is assumed to be a relatively simple task, the data gathered with normally-developing preschoolers suggests that picture-related performance was influenced by certain physical characteristics of the pictures as well as their arrangement.

Background

The AAC field has long been challenged to develop high-tech systems that support the emerging language capabilities of individuals with significant cognitive limitations or who are chronologically very young. In recent years, we have witnessed the emergence of several devices capable of creating and displaying various types of graphic language representations. Whether low-tech or high-tech, however, the language representations used on AAC systems should be selected to conform with the user's abilities.

Previous research indicates that picture-based language representations pose varying levels of challenge based on their perceptual and conceptual similarity to their referents (1,2,3). We also have some evidence that the number of pictures competing for the user's attention impacts the difficulty of the task (4,5). Our ability to make sound clinical judgments would be enhanced with more information about how people with disabilities understand and use pictures.

Research related to these issues is somewhat cumbersome to conduct, given the complexities of generating vast numbers of stimulus items and manipulating multiple items across many trials. To enhance the efficiency and flexibility of investigations in this area, we have developed a tool for the creation, manipulation, and presentation of graphic images in a virtually limitless number of configurations. The system, called Lascaux, supports the development of applications for assessment, training, and augmentative communication purposes (6,7).

Statement of the Problem

The characteristics of a picture may impact its comprehensibility. For example, full-size color photographs tend to include much more information than do small black-and-white line drawings. Most clinicians assume that "more is better" in this respect and do not tend to evaluate individual differences, although the literature is replete with surprising counters to this supposition (8,9). Mineo's research with individuals having severe cognitive and communication limitations indicated that her subjects demonstrated unique ability profiles relative to the picture characteristics of size, color, and quality (5). If ability profiles are unique to individuals, and do not conform to some immutable hierarchy of "symbol difficulty," then it becomes essential that clinicians evaluate representational skills prior to making recommendations for AAC system specifications. Such evaluation would be accomplished by systematically varying symbol characteristics to determine those that are most conducive to correct responding. However, systematic variation of these characteristics in stimulus materials developed and presented manually is costly both in terms of materials and the time needed for administration of the research protocol.

Rationale

The development of Lascaux and its associated applications was prompted by the desire to be able to create specialized assessments, training packages, and AAC displays with maximum precision and a minimum of effort. Lascaux captures images from real-world objects or photographs. The system then generates graphics corresponding to very exact specifications in regard to color, size, and detail, and arranges them on the screen according to the layout specified in the particular application.

Design and Development

In brief, Lascaux is a computer based system running on a Macintosh platform supported by a hardware configuration of a 20" monitor with touchscreen, a color video camera, a color scanner, a microphone for speech input, speaker for speech output and a color printer. This configuration supports the software that is used to perform the image manipulation.

Assessing Picture Skills

The particular computer-based application described in this paper permits the examination of picture-matching skills along various dimensions without having to exact the costs described above. Using the Lascaux system, the application was designed, images were brought into the system and manipulated along the specified dimensions, the assessment protocol was presented to the participants, and the data were collected and analyzed.

The task presented by the system required the participant to match an item from an array to a sample item appearing above the array (see Figure 1). The complexity of the task varied as the color, size, and detail dimensions were manipulated, and as the number of items in the array increased. For example, at the first level of the assessment, the participant had to match a 4" color photograph to, in order of increasing difficulty, another photograph from an array of four 4" pictures, then 2" pictures, then 1" pictures. If successful at the level of 1" pictures, the system presented stimuli manipulated along the color dimension, ranging from full-color photographs to ones containing 66% color, 33% color, and no color (black-and-white).

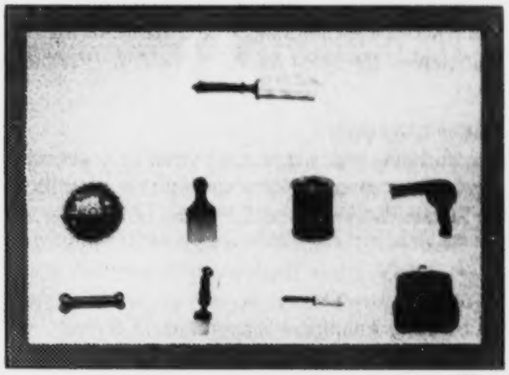


Figure 1: Sample Screen

The next dimension assessed was detail, with the ends of the continuum being a photographic-quality image and a line drawing. At the midpoint of the continuum was a cartoon-like image. This progression is illustrated in Figure 2.

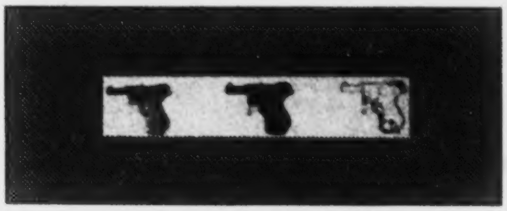


Figure 2: Quality Manipulation

The last step in the assessment entailed increasing the number of items in the array incrementally from 4 to 12, with 1" color photograph stimuli. Participants interacted with the system using a touch screen, obviating the need for translation of the intended selection into a keystroke.

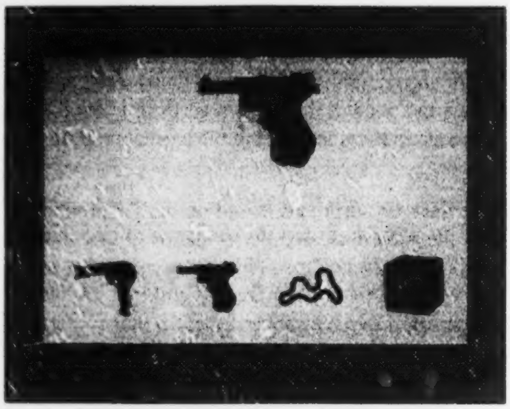


Figure 3: Screen with Expanded Array

Evaluation

The initial evaluation of the system was conducted in-house, to determine whether the touchscreen access, timing of presentation, and other features were functioning as specified and were tolerated by children as young as two years of age. Minor adjustments were made during this period.

The first field test of the system was conducted with normally-developing preschoolers having age-appropriate sensory and language capabilities. The children were seated in front of a 20" monitor on which the screens of the application were presented. Selections were made via touchscreen in response to a prompt given by the computer to "find the same." The children interacted with a familiarization module prior to the beginning of the assessment. This interaction acqainted them with the computer's "voice," the visual prompting conventions used throughout the assessment, and the types of reinforcements provided following their responses.

After completing the familiarization, the children were presented with a sequence of screens following the progression described above. Responses were scored as correct or incorrect. If incorrect responses were made, the alternate behavior was recorded. Each item serving as a match had both a shape foil and a color foil in the array. This design allowed us to analyze errors to determine if the children were overly reliant on a particular type of information when making their selections.

Assessing Picture Skills

Preliminary analysis of the data reveals several trends. When errors were made, it tended to be on those trials that pertained to color reduction, detail reduction, or increasing number of items in the array. When children lost information due to reduction of color or detail, their errors revealed that they were depending heavily on the shape of the item as a cue. Interestingly, even though the children performed well with four 1" color photographs, their performance deteriorated as more items were added to the array. Again, they appeared to rely on shape cues to assist them in locating the correct response.

Discussion

These data are surprising based on our assumptions about the picture-related performance of normally-developing preschoolers. This was a *matching task only*, which does not require the children to know the items or provide a spoken label for them. Matching tasks are assumed to be the most basic of the picture-related tasks, yet errors are occurring as the characteristics of the pictures or their arrangement are modified.

Even greater error rates might be expected if the task carried more of a linguistic load, as in the case of selecting an item from an array in order to communicate a message. This clearly has implications for those who use picture-based AAC systems. The research agenda is full; we need to examine the picture-related performance of more children, both with and without disabilities, at various ages, across a variety of tasks, and with a variety of picture types. Learning more about the existence of individual profiles of strengths and weaknesses should help clinicians design training and device displays that are maximally responsive to the user's current needs and abilities. The results of this study are intriguing, but we have a long way to go before we can offer a systematic means by which to assess the picture-related performance of individuals with disabilities.

References

1. Dixon, L.S. (1981). A functional analysis of photo-object matching skills of severely retarded adolescents. *Journal of Applied Behavior Analysis, 14*, 465-478.

2. Sorce, J. (1980). The role of operative knowledge in picture comprehension. *The Journal of Genetic Psychology, 136*, 173-183.

3. Steinberg, B.M. (1974). Information processing in the third year: Encoding, memory, transfer. *Child Development, 45*, 503-507.

4. Franklin, N.K. (1990). *A comparison of five augmentative communication symbol assessment protocols with learners with severe intellectual disabilities.* Unpublished doctoral dissertation, University of Nebraska, Lincoln, NE.

5. Mineo, B.A. (1990). *A feature-based approach to the evaluation of representational capabilities.* Paper presented at the Fourth Biennial International ISAAC Conference, Stockholm, Sweden.

6. Demasco, P., Mineo, B., Gray, J., & Bender, R. (1994). The design and development of a computer-based system for assessing and training two-dimensional language representation. In M. Binion (Ed.), *Proceedings of the RESNA'94 Annual Conference* (95-97). Arlington, VA: RESNA Press.

7. Mineo, B., Demasco, P., Gray, J., & Bender, R. (1994). Systematic assessment of picture-based language performance via computer. In the *Proceedings of the 1994 ISAAC Conference* (111-113). Maastricht, The Netherlands: IRV.

8. Gibson, J.J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin.

9. Kose, G., Beilin, H., & O'Connor, J.M. (1983). Children's comprehension of actions depicted in photographs. *Developmental Psychology, 19*, 636-643.

Acknowledgments

This work has been supported by the U.S. Department of Education, National Institute on Disability and Rehabilitation Research by way of Field-Initiated Grant #H133G10189 and Grant #H133E30010 for the Rehabilitation Engineering Research Center on Augmentative Communication to the University of Delaware. Additional support has been provided by the Nemours Research Programs.

Author address

Beth Mineo

Applied Science and Engineering Laboratories
A.I. duPont Institute
1600 Rockland Road, P.O. Box 269
Wilmington, Delaware 19899 USA
Internet:mineo@asel.udel.edu

SIG-05
Quantitative Functional Assessment

INTEGRATED VIDEO AND COMPUTERIZED FUNCTIONAL ASSESSMENT

Dan W. Shafer, O.T.R. and H.F. Machiel Van der Loos, Ph.D.
Rehabilitation R&D Center
Veterans Affairs Medical Center
Palo Alto, CA

Abstract

A prototype of the Functional Performance Assessment Tool (F-PAT) has been designed to conduct functional outcome efficacy studies of treatment interventions using a multimedia approach. F-PAT allows a clinician to evaluate repetitive strain injury symptoms through video analysis of functional activities. A set of twelve functional tasks was derived by clinicians to elicit physical symptoms among patients with upper extremity repetitive strain injury (RSI) involvement. Aside from its interactive video analysis capabilities, F-PAT includes a database for patient information storage and templates for treatment planning and efficient interdisciplinary communication. We believe that analysis of video footage of patient performance can assist a clinician in preparing a treatment plan for the patient, sharing patient information with multidisciplinary team members, and creating and implementing an individualized home rehabilitation program.

Background

Video Analysis in Evaluating Human Activity

Videotape analysis has been practiced by researchers in areas as diverse as ethnology, cognitive science, psychology, and mechanical design practice (1). The major drawback of video is the length of time needed to index and annotate segments of interest for later use in analysis. A recently commercialized software tool (2) performs these data management functions, thereby substantially reducing the overhead in the use of video as a raw data source. While the video data remains on an 8mm videotape, its index becomes part of the patient record and can be reused in a number of ways. Video has been applied to rehabilitation only for programmatic instructional purposes and in research. The overhead associated with video analysis has precluded its use as an economically viable individualized training tool to date. The combination of video annotation and the patient database maintained on the computer represents a new set of tools for clinical application.

Demographic Factors and Repetitive Strain Injuries among Individuals with Paraplegia

There are an estimated 225,000 persons with spinal cord injury (SCI) in the U.S., with 6,000 to 10,000 new injuries occurring every year (3). Of these, 57% have paraplegia. The use of manual wheelchairs by individuals with paraplegia means that the upper extremity (UE) musculoskeletal system is in constant use for mobility functions, including pressure reliefs, hand-rim propulsion and transfers. Propulsion-related repetitive strain injuries (RSI) will increasingly interfere with vocational opportunities as more people with disabilities enter the work force. Workplace-related carpal-tunnel syndrome, related to keyboard use for example, is already a leading repetitive strain injury.

Even with exercise and therapy, many manual wheelchair users suffer UE RSI at some point in their lives. Shoulder and wrist surgeries are indicated for approximately 30% of the 90 RSI cases seen at the Palo Alto VA SCI Center each year. Initially, however, about 70% of these elect not to undergo surgery in favor of conservative treatment. Assessments focused on functional outcomes may be able to track the effects of different therapies. This population of veterans with RSI, with the long time constants involved in both progressive reduction of function and the rehabilitation process, is well suited as a test case for F-PAT.

Statement of the Problem

Based on the changing environment of health care, modifications to current rehabilitation practice will have to be implemented. One problematic area in rehabilitation performance analysis involves the lack of quantification of functional outcomes. Quantification of performance would allow therapists to accurately convey rehabilitation information to a patient, other therapists, and members of a treatment team. It would also provide for more accurate treatment planning, goal setting, and equipment ordering based on specific areas of dysfunction. Quantification of such performance is conceptually difficult, given the need for therapists to assign arbitrary values to all facets of activity performance and to aggregately yield a single number describing this performance. Functional measurement scales such as the FIM attempt to do this, but frequently do not measure specific components of activity performance such as substitution patterns elicited, attitudes regarding task performance, and specific areas in need of improvement.

Vital functional assessment information is obtained through observation of activity task performance. Choosing tasks is difficult in that each task must represent a functional activity, must elicit specific dysfunction (or lack of evidence thereof), and must be able to be videotaped under standardized methods and assessed by virtue of the video footage alone. Accordingly, the tasks must be subject to scrutiny, as they are the sole providers of the raw data leading to the assessments of functionality for each subject.

Video analysis in rehabilitation is not prevalent at this time for several reasons. First, specific expertise and experience is necessary for effective video use and analysis. Also, video annotation is laborious; a commonly accepted time allotment is ten hours for every hour of raw video footage. The combination of expertise, finances and time required is a major deterrent for consideration of video use by most rehabilitation settings.

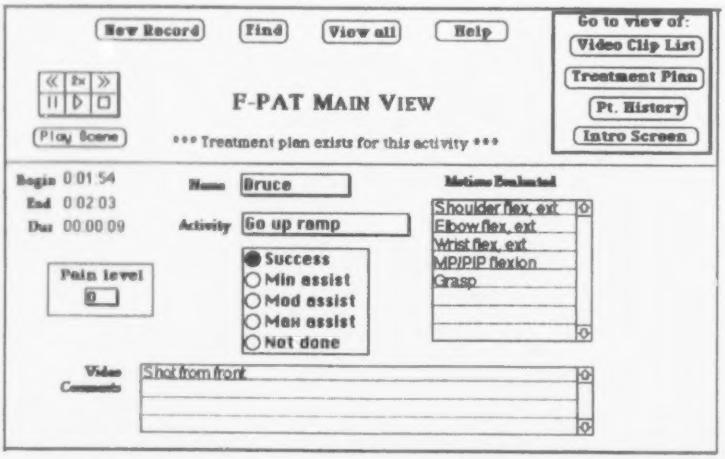
Shorter periods of hospitalization place a much larger responsibility on the patient to follow through with rehabilitation. Consequently, great importance is placed on an individual's adherence to a prescribed home therapy program. The patient must be motivated to participate in home therapy, and is hypothesized to benefit from a feedback mechanism to help him gauge his progress and gain awareness of his deficit areas. An interactive home therapy tool incorporating video footage would allow a patient to periodically view his progress and functional gains, while simultaneously highlighting areas in need of improvement. With F-PAT, therapists could easily structure or design personalized home therapy programs to provide an appropriate challenge for the patient with increasing functionality.

Approach

Based on our experience with evaluations of workplace accommodations based on computerized and video-based assessment methods (4), we have developed a prototype functional performance assessment tool to explore the use of video in conjunction with a database program to annotate, time stamp and replay video segments. The concept of F-PAT includes a database containing patient records as well as templates for treatment planning, patient history information, indexing raw video footage, communicating with other rehabilitation professionals, and creating new patient layouts and records. The database features twelve functional tasks derived in collaboration with the Palo Alto VA SCI Center Upper Extremity Clinic to demonstrate the effects of RSI on persons with paraplegia who are manual wheelchair users. These activities were selected based on their demands on the UE as well as ease of videotaping. It was felt that the performance of these activities by patients with RSI, acting as study participants, would elicit visual evidence of dysfunction related to the subjects' RSI conditions.

Preliminary Results

Preliminary data has been gathered from three subjects who volunteered to be videotaped performing the current F-PAT activities. Two of the subjects are manual wheelchair users who have no symptoms of RSI. The third subject does not have a spinal cord injury but does have moderate to severe RSI involvement, particularly in her right UE. Video analysis of these subjects shows that RSI symptoms can be identified from difficulties in performance of these activities under standardized conditions. Also planned is research demonstrating the effectiveness of F-PAT in reducing costs by comparing clinical practice with and without its use. It is our goal to make F-PAT compatible with and a part of the large scale VA effort to computerize patient records and rehabilitation management information.



*** Treatment plan exists for this activity ***

Begin 0:01:54
End 0:02:03
Dur 00:00:09

Name: Bruce
Activity: Go up ramp

Pain level: 0

- ● Success
- ○ Min assist
- ○ Mod assist
- ○ Max assist
- ○ Not done

Motions Evaluated:
- Shoulder flex, ext
- Elbow flex, ext
- Wrist flex, ext
- MP/PIP flexion
- Grasp

Video Comments: Shot from front

Figure 1: F-PAT template showing activity, video access buttons, and related information

BEST COPY AVAILABLE

Future Plans

Initially, two therapists will be trained to use F-PAT in the clinic for testing with ten patients over a one year period. The reviews from the therapists will lead to F-PAT redesign and expansion to incorporate advanced communication and reporting features during this period. The activities will be scrutinized for elicitation of functional deficits, and new activities will be researched as to their effectiveness in this area. We plan to complete F-PAT according to user recommendations and to continue field testing, incorporating an interdisciplinary utilization scheme.

Implications

The concept of indexable, reviewable video footage of patients performing functional tasks during different stages of rehabilitation is proposed as a potentially powerful means of promoting reliable treatment planning by therapists and allowing the conveyance of accurate therapy information to other rehabilitation professionals. Stopping just short of actual quantification, organized video footage linked with a comprehensive database of functional activities and related quantitative measurements provides comparative categorization of information. Data and video organized in this manner allow rehabilitation professionals to make cohesive, unified decisions based on reliable therapy information regarding treatment needs. Therapists are able to base treatment planning on up-to-date yet reviewable video footage. The inclusion of a communication tool in this database provides the possibility of a network of rehabilitation professionals all able to access footage and relay information. Time savings for the therapist would be evident in the areas of home program development, ease of interdisciplinary communication, visual identification and justification of functional deficit areas, and the ability to base treatment planning on this reliable, reviewable raw data. The therapist's overhead costs in terms of time necessary to take the video footage and annotate and integrate it into the database would be compensated for by time saved in these areas.

Discussion

We hope to establish the feasibility of integrating F-PAT into clinical practice using the methodology described above. The factors mentioned as deterrents to video use in rehabilitation settings – expertise, finances, and time expenditure – are all obstacles to full integration of F-PAT into a clinical setting. However, we propose benefits from F-PAT utilization including increased validity and reliability standards in treatment planning, efficient record keeping and communication capabilities, and the ability to construct a superior personalized home treatment program. In addition, advances in the state of multimedia technology have made available many low-cost innovations from which a future F-PAT platform may be developed. QuickTime video viewing capacity is built into newer Macintosh systems, and Connectix Corporation has released an inexpensive miniature video camera which plugs into the computer's serial port and produces video clips at 12-15 frames per second (5). In addition, video editing resources now available for Macintosh computers provide ease of use at a low price. The integration of F-PAT and digitized video footage into currently existing computerized evaluations, such as the Greenleaf EVAL (6) and others, is proposed to be a significant focus of research in the future of this assessment tool.

References

1. Suchman, L. Plans and Situated Actions. *New York:* Cambridge University Press, 1987.

2. Stripling, T., Fonseca, J.E., Tsou, V., & Copperhite, A. (1983). A demographic study of spinal cord injured veterans. *The Journal of the American Paraplegia Society, 6*(3), 62-65.

3. Hammel, J., Van der Loos, H.F.M., Perkash, I. (1983). Evaluation of a Vocational Robot with a Quadriplegic Employee. *Archives of Physical Medicine and Rehabilitation*, Vol 73, pp. 683-693.

4. CVideo, Knowledge Revolution, Inc., San Francisco, CA

5. QuickCam, Connectix Corp., San Mateo, CA

6. EVAL, Greenleaf Medical Systems, Palo Alto, CA

Acknowledgments

Support for this project is provided by Core funding of the Rehabilitation R&D Center of the Palo Alto VA Medical Center. The authors wish to thank Joy Hammel, Deborah Kenney, and all the Occupational Therapists of the Palo Alto VA SCI Center for their contributions to the project.

Author's Address

Dan Shafer
Rehabilitation R&D Center
VA Medical Center
3801 Miranda Ave., MS 153
Palo Alto, CA 94304-1200
office: 415-493-5000 #5972
fax: 415-493-4919
e-mail: shafer@roses.stanford.edu

TRAINING REHABILITATION ENGINEERS TO MEET ANTICIPATED FUTURE NEEDS

Jack M. Winters, Ph.D.
Biomedical Engineering Program,
Catholic University of America, Washington DC 20064

ABSTRACT

The challenge of identifying long-term "niches" for rehabilitation engineers within a changing rehabilitation service delivery process is addressed, since it influences training strategies. Ongoing changes in engineering education are summarized, especially as related to the positive impact of integrating design and computers throughout the curriculum. Two unique abilities are identified that help demarcate the engineer from other providers: open-ended problem-solving skills that include quantitative analysis when appropriate, and objective quantitative evaluation of human performance. Five key training components are identified and developed. Educational implementation strategies are discussed. Finally, a case is made for "hybrid" engineers-therapists.

INTRODUCTION

There are three main employment categories for rehabilitation engineers (REs): *i)* rehabilitation service delivery, usually working within a hospital environment; *ii)* product development and sales, usually working for companies, and *iii)* rehabilitation research, often at a university. The first two normally require a bachelor's or master's degree, the last a doctoral degree.

At present there is not a single, accepted approach for training students interested in careers in RE. This is to be expected, given the inherently interdisciplinary nature of the field, and the lack of a credentialing process and a third-party payment "niche." The primary objective of this paper is to suggest appropriate educational approaches for training future REs. A secondary objective is to confront what the future might hold for REs.

BACKGROUND

Career Transitions are Common. It is now generally accepted that the typical professional will undergo several significant career transitions over a lifetime. Thus, the educational process should not only help prepare the student for short-term career objectives, but also provide a foundation that will help make long-term career transitions more realizable. This implies the need for: *i)* a solid initial interdisciplinary foundation, and *ii)* the opportunity for continuing education, especially in "up-and-coming" areas.

Engineering Education. Existing undergraduate engineering programs have historically been quite structured, in part due to the accreditation requirements of the Accreditation Board for Engineering and Technology (ABET), which include basic math/sciences (1 year equivalent), engineering sciences (1 year equivalent), and engineering design (1/2 year equivalent). Traditionally, the first two years have been heavy in mathematics and basic science, the third year emphasizes core engineering science courses in the major, and the senior year engineering design and technical electives. The ABET process has recently changed. Significant changes are occurring in undergraduate education including: i) computer integration across the curriculum; ii) design across the curriculum, including lower division; iii) integrated engineering science/design; and iv) a greater recognition of the importance of liberal studies. Each of these appears beneficial from the perspective of training REs. For instance, I expect higher-quality 3-D computer graphics in my junior-level Biomechanical Design course than I do in my graduate courses. Many universities, including ours, now have a freshman design course. Often freshman design projects build on students' 18 years of personal experience with the human-technology interface, gravitating toward designing simple devices around the needs of humans, including those with disabilities.

Degree Options for Rehabilitation Engineers. Degrees must be obtained in an available discipline such as biomedical, mechanical, electrical, computer, or industrial engineering. The most common path now appears to be biomedical engineering or bioengineering (BME). In the brochure entitled *Biomedical Engineering Careers*, RE is listed as one of the six "specialty areas" within BME, and is called "new and growing." BME is unique in several ways: *i)* exposure to physiology and biomedical technology; *ii)* high percentage of female students (40%, vs. 12% for engineering as a whole); *iii)* high percentage of students who continue their education at the graduate level (60-70% at most schools), and *iv)* it is one of the few engineering fields that is growing in numbers of students. There are currently 22 undergraduate programs accredited by ABET in BME; over 40 programs offer graduate degrees.

Lack of a Service Delivery Niche. A clinical RE who solves client problems via a mixture of clinical experience and common sense, without directly applying engineering problem-solving techniques, risks becoming replaced. This is not meant as a criticism; it is a pragmatic reality. To justify a niche in our health care infrastructure, a *unique service* needs to be offered that is not available by another type of provider. Primary areas for current clinical RE's include seating/positioning, worksite accommodation, and the provision of augmentative/alternative communication aids. While certainly appropriate, the first two of these in particular can be areas that make little use of quantitative skills, and where other service providers (e.g., occupational therapists, rehabilitation technologists) can become quite competent.

This raises the question: What unique attributes does an engineering education buy its customer? Possible answers include: About 80 credits worth of a foundation in quantitative engineering analysis capabilities? Some valuable problem-solving skills, as useful in management as in engineering analysis? It is suggested here that it can provide the student with two classes of skills of value for the foreseeable future: i) *human-technology interface design expertise* (i.e., open-ended problem-solving that likely involves the human-technology interface); and ii) *objective evaluation* of human performance.

Changes in Service Delivery? It is suggested that changes in rehabilitation service delivery over the next 10-15 years will be more dramatic than is commonly anticipated, and that REs have the necessary problem-solving tools and pragmatic skills to become leaders in this process. While clearly health care reimbursement policy is driving current change, perhaps less recognized is that technological innovation is occurring in some key fields that will have a remarkable impact on future directions in assistive technology and service delivery. Consider the following, all of which are likely to occur, in some form, within 10-15 years:

1. Due to changes in information technology, the following will be a routine part of care:
   - "tele-visits" (video teleconferencing);
   - providers with "intelligent computer assistants"
   - therapy at home (with results automatically stored/transmitted, as appropriate).
2. Due to dramatic changes in advanced/smart materials, and CAD/CAM/rapid prototyping:
   - customized postformable composite orthoses, formed "on the spot";
   - programmable "smart" materials will be used for therapy (e.g., to prevent contractures), to warn users before a fatigue failure, etc.
   - modular orthoses will be in common use
3. Due to advances in computer speed and sensor technology, combined with the need for objective measures of impairment and functional outcomes:
   - objective quantitative (sensor-based) measures of impairment and function will be routinely used to complement observational measures

Are these predictions realistic? From a technological perspective, absolutely -- although certainly not exactly as predicted here. Rather, these scenarios illustrate a point: in all cases, REs *could be key players in the service delivery process, or could be out of the loop* (other than for research /development and sales). All involve quantitative measurements and signal conditioning, and a dependency on technology -- areas where the knowledge and problem-solving skills of engineers could be valuable. From an educational perspective, how should engineers be trained to meet a future that is likely to include such significant change?

APPROACH

It is suggested that the RE training process should include:

1) *Core science and engineering knowledge* in the following seven areas: engineering mechanics (statics), electric circuity and instrumentation; mechanics of materials (solids), signals/filters or systems/control; microprocessors/control; computer-aided graphics and design (3-D), and physiology.

2) Significant experience in synthesized *open-ended problem-solving*, that includes using engineer science knowledge as *tools* to assists with analysis and decision-making (a skill requiring practice, as much an "art" requiring practice as a "science.");

3) *Hands-on design projects*, including fabrication of "deliverables". The open-ended design process is inherently iterative, and involves needs assessment, identification of criteria, the consideration of alternative solutions, analysis, fabrication, and some mechanism for evaluating the final product. Most engineering programs, although certainly not all, require that the project culminate with a "deliverable" product, normally a device (3). It can prove challenging for instructors to identify good design projects that students find interesting and deem worthwhile, and that fit within the pragmatic constraints of a one- or two-semester project (complexity level, financial resources, time commitment). Within this context, many programs have found that RE projects seem to offer an ideal design experience, especially when users or service providers are in the iterative design loop (1,2); indeed NSF sponsors such a program for customized student designs for specific persons with disabilities. At the recent *Design in Biomedical Engineering Curricula*

(3) Workshop, organized by this author, recurring themes were the importance of "deliverables" and the value of evaluation followed by iteration -- both areas where RE projects tend to be ideal (1).

4) A "breadth" RE course that spans the RE field, and that preferably includes many guest lecturers with a variety of professional experience (e.g., our course here includes 10-12 guest lecturers).

5) A clinical internship experience.

DISCUSSION AND IMPLICATIONS

It is my experience that considerably more BME students would like to go into RE than there are available jobs. It has also been suggested that due to changes in engineering education, the potential for training REs within the engineering educational environment has been enhanced. This provides a dilemma. A central question is this: What will REs of the future do?

A first strength of REs is suggested to be *open-ended problem-solving involving the human-technology interface*. Within this context, if the provision of a certain technology becomes routine, or the approach purely systematic, the *engineer's talents become less useful*. Thus the potential dilemma regarding who is to provide customized seating/positioning, and the reason why engineers are not involved in prescribing hearing aids. The provision of most assistive devices does not involve engineers, and this is appropriate: it is in the best interest of the rehabilitation technology supplier to gear a product so that the capabilities of the primary provider are adequate for basic alteration and customization. For how many products do suppliers deem REs to be the primary provider of their technology to the client? Very few. Thus, for most successful assistive devices, REs normally needn't be in the loop. The bottom line, from the perspective of training, is that while it is important to provide basic training in classic areas such as seating/positioning and worksite accommodation, *of greater importance is to help the student develop solid skills at open-ended problem-solving for a variety of rehabilitation examples*. Educationally, these examples should be formulated within the context of a *design problem*, and the student should have to go through the *whole process*, from beginning to end.

The second unique RE skill area is *quantitative evaluation and outcomes assessment* of rehabilitation interventions. Objective evaluation is needed at many levels, ranging from initial diagnosis /screening to assessment of functional outcomes. There are pragmatic reasons (e.g., computational speed, NIH directives, third-party objectives) for believing that there will be a trend toward increasing objective evaluation. If portable evaluation systems (PES) were to come into common clinical use, which seems likely, test batteries will include a mixture of classical observational metrics complemented by objective measures that are essentially reduced from raw sensor data. It is difficult to imagine are more suitable job area for clinically-based future REs. It is suggested that if clinical RE is to grow, this will be the primary area. The bottom line, from a training perspective, is that students need to become embedded in sensor-to-computer interface technology and in signal processing (both analog and digital filtering). They also need to have a solid understanding of how objective information can be used to document human performance and to facilitate understanding of the human-technology interface, and why this can be of clinical relevance. Interestingly, current trends within engineering education will facilitate this training process.

Rehab Engineers/Therapists. Nationally, and here at CUA, approximately 30% of all BME undergraduates end up going to medical school. Might engineers also be well equipped, with extra training, to function as orthotists/prosthetists or physical/occupational therapists? Yes, for several reasons: ***i)*** the undergraduate curriculum is changing in ways that could enhance RE training; ***ii)*** the trend in these areas is toward graduate degree or certificate programs; ***iii)*** as in medicine, technological changes will make an engineering background more valuable; and ***iv)*** engineers may come to like these career options. Of note is that RE/therapists should have unique long-term flexibility for career transitions in fields likely to undergo significant long-term change, and/or to easily switch between clinical practice and product design for a company. Additionally, this unique background should help enable them to be at the forefront of changes, playing a proactive role.

REFERENCES:

(1) Winters JM. Design-based rehabilitation engineering education, *Proc. 3erd Ann. Conf. Biomed. Engng. Soc.*, 1992, Salt Lake City: Abstract 127 (A7.4).

(2) Winters JM. Rehabilitation engineering training: A look into the future, *Proc. 28th Ann. Assoc. Adv. of Med. Instrum.*, Boston, 1993, p. 97.

(3) Winters JM, Goel VK, Masi J, Rowley BA, Voigt H. ***BME undergraduate design resource guide***. Published by *Council of Chairs of Bioengineering and Biomedical Engineering Programs*, 1995.

Jack Winters, Ph.D.
Biomedical Engineering Program
Catholic University of America
Washington, DC 20064
202-319-5843; winters@pluto.ee.cua.edu

THE EFFECT OF A LIFTING BELT ON THE FUNCTIONAL CAPABILITIES AND 3-D TRUNK MOTION PARAMETERS DURING A FATIGUING EXERCISE

Patrick Sparto, M.S., Mohamad Parnianpour, Ph. D., Thomas Reinsel, M.D., and Sheldon Simon, M.D.
The Ohio State University, Columbus, Ohio 43210

Abstract

Lifting belts are commonly worn in industry to protect workers from suffering lifting-related low back injuries, despite evidence that is equivocal at best. The functional capabilities and trunk motion parameters during a sagittally symmetric repetitive lifting exercise were measured for ten subjects with and without the support of a lifting belt. The maximum voluntary range of motion, and range of motion during repetitive lifting was decreased in the sagittal and frontal planes, while wearing the belt. There was no difference in strength, while the number of lifts performed was less for the belt condition. It is suggested that belts that are properly worn may provide protection to the spine during lifting with extreme forward flexion and some unintended lateral bending.

Introduction

There has been debate over the last 10-15 years on the effectiveness of lifting belts in reducing injuries to the lower back that may be the result of a lifting episode. Much of the debate has concerned intervertebral disc compression forces and intra-abdominal pressure. However, it is the complex loading that results from severe forward flexion, lateral bending, and twisting that has been most implicated in putting the spine at risk for failure. This study concerns the effect of lifting belts on the functional capability of users (i.e. range of motion, strength, endurance time). In addition we wanted to discover if the belt provided any protection against severe forward flexion, and unintended lateral bending and twisting during a fatiguing sagittally symmetric repetitive lifting task.

Methods

Ten male subjects, with no report of low back pain in the previous six months (mean age = 27.8 years, range 23 - 36 years) volunteered for the study. Their mean (s.d.) stature and mass were 179.5 (7.9) cm and 76.9 (11.3) kg, respectively. The had no reported low back pain in the previous six months.

We investigated the effect of a flexible lifting belt on measures of the subjects' functional capabilities. That is, we examined the maximum voluntary triaxial trunk range of motion, power output during lifting, and repetitive lifting endurance time. Furthermore, the triaxial dynamic trunk range of motion and velocity were measured during a repetitive lifting exercise to determine if the belt provided any protective mechanisms when the subjects were fatigued.

Subjects were tested in two sessions at least a week apart, to allow for recovery from the repetitive lifting test. The lifting belt was used in the first session on a random basis. If the condition was the With Belt (WB) condition, the subject wore the flexible lifting belt over his clothes. The belt is 20 cm wide at the midline of the back and is centered at the approximate location of the lumbosacral joint. The subjects fastened the belt (with velcro) as tight as possible, without restricting their ability to breathe comfortably. The subjects were then outfitted with the devices necessary to measure the three - dimensional trunk motion and hip motion.

After several minutes of stretching, the maximum voluntary triaxial trunk range of motion of the subject was measured. The dynamic measures were taken from a repetitive isokinetic lifting and lowering exercise (37.5 cm/s) from mid-shank to waist level in the sagittal plane. The isokinetic resistance was provided by a LIDOLift lifting simulator. The subjects were instructed to exert maximally through the entire range of motion on the lifting portion, and to provide minimal resistance to the dynamometer on the lowering portion. Isokinetic resistance was chosen to maximally stress the low back musculature. Subjects terminated the test when they felt they could no longer continue.

As part of the functional capability strength assessment, the maximum instantaneous power output was determined from the first three lifts and last three lifts of the repetitive lifting task. Also, the number of lifts to fatigue was noted.

To determine if the belt provided any protection against complex loadings that occur with severe flexion, lateral bending and/or twisting, the maximum triaxial position of the trunk and sagittal position of the hip during the first three and last three lifts was measured. The position data was time differentiated to obtain the trunk and hip velocity. The dependent measures were analyzed with an

170

ANOVA, which tested for the effect of belt, and the interaction between the belt and fatigue.

Results

The effect of belt on the functional capabilities is shown in Table 1. The maximal voluntary trunk range of motion was significantly decreased for the belt condition in the sagittal and frontal planes. There was no significant difference in the maximum strentgh capability during the repetitive lift, as evidenced from p-value of the maximum power output. Finally it is seen that there was a greater endurance time for subjects when they were they were not wearing the belt.

The results of the trunk position and velocity measures during the repetitive lift are shown in Table 2. In the sagittal plane, there was a significant decrease in the trunk sagittal range of motion, a decrease in the amount of forward flexion, and decrease in extension and flexion velocities, when wearing the belt. There were similar decreases in the lateral plane, but not the transverse plane. The p-values indicate that the restriction in motion was not compensated by the hip.

The interactions between the belt and fatigue are for the most part not significant, indicating that the belt does not provide any more or less protection against out of plane movement (non-sagittal) or severe flexion, when the subject is fatigued. The significant p-value for the trunk sagittal range of motion is due to a decrease in the non-belt range of motion in the fatigued state.

Discussion

This study has shown, that when worn in the manner described above, lifting belts may decrease the maximal voluntary range of motion in the sagittal and frontal planes. More importantly, during dynamic lifting conditions, there was evidence of reduced motion in the same planes of motion. This reduction of motion may reflect a mechanism by which the spine may be protected during lifting in extreme flexion with unintended lateral bending. No evidence of differences in the strength were seen. However, the number of lifts performed without the belt was greater than with the belt.

Acknowledgments

The authors acknowledge partial support from NIDRR, REC grant #H133E30009 and the Ohio Bureau of Workers' Compensation, Division of Safety and Hygiene. In addition, William Marras is acknowledged for his assistance.

Patrick Sparto
Room 210 - Baker Systems and Engineering
1971 Neil Avenue
The Ohio State University
Columbus, OH 43210

Table 1. Results of ANOVA for the effect of belt on the functional capability parameters

Functional Capabilities	Effect of Belt
	p-value
Maximum voluntary trunk sagittal ROM	0.012
Maximum voluntary trunk frontal ROM	0.009
Maximum voluntary trunk transverse ROM	NS
Maximum instantaneous power output	NS
Number of lifts	0.044

Table 2. Results of ANOVA for the effect of belt and the interaction between belt and fatigue on the trunk motion parameters during the repetitive lifting test.

Repetitive lifting test	Effect of Belt	Belt * Fatigue
	p-value	p-value
Trunk sagittal ROM	0.001	0.006
Trunk frontal ROM	0.032	NS
Trunk transverse ROM	NS	NS
Maximum trunk sagittal flexion	0.013	0.008
Maximum trunk extension velocity	0.002	NS
Maximum trunk flexion velocity	0.004	NS
Hip sagittal ROM	NS	NS

COMPRESSION IS SUPERIOR TO EVACUATION FOR COUGH ASSIST

Patsy Y. Kawaoka
Bioengineering Department
University of Washington
Seattle, WA U.S.A.

ABSTRACT

Patients with paralysis of abdominal and intercostal muscles are unable to cough effectively and require assistance for removal of pulmonary secretions. Evacuation at the mouth or thoraco-abdominal compression can be used for cough assist purposes. A previously described model of forced expiration (J. Appl. Physiol. 62: 2013-2025,1987) was modified and used to compare the effectiveness of both assist strategies. Results obtained using normal airway parameters showed that both assist strategies yielded identical expired flow-volume responses. However, compression at 40 cm H_2O pressure led to significantly higher tracheal compression and more than two fold higher tracheal flow velocity than evacuation at the same level of pressure. Since airway clearance should be a function of velocity, compression was concluded to be superior to evacuation for cough assist.

BACKGROUND

Patients with impaired cough performance include those with spinal cord injury and respiratory muscle paralysis as well as others with muscular dystrophy, ALS, myasthenia gravis, and polio. Patients with this disability lack the normal means of eliminating bronchial secretions and are prone to respiratory infection. Evacuation at the mouth or thoraco-abdominal compression could be used in such patients for cough assist. Compression is closer to normal cough function, but evacuation has been argued to yield identical expired flow-volume responses and be more convenient. The question that is raised here is whether there is any difference between the two strategies in terms of flow velocities in the airways. Airway flow velocities should best correlate with clearance of secretions.

APPROACH

Flow dynamics during cough should be the same as for the forced expiration maneuver. Previous work (1) described a model of forced expiration based on an analogy between isovolume pressure-flow curves of the lungs and emitter-collector voltage-current relationships in bipolar transistors. This analogy is depicted in Figure 1. In the lungs, airway cross-sectional area and compliance (set by transluminal pressure) determine flow limitation through the wave-speed mechanism just as base current limits the maximum collector and emitter current. Thus, setting a level of transistor base current is analogous to a given value of airway transluminal pressure. The primary value of this analogy is the ready availability of powerful circuit simulation software such as the SPICE package which has been refined for over 20 years. This analogy permitted the easy solution of the non-linear dynamics connected with collapsible airways. The complexities of matching upstream and downstream boundary conditions are automatically taken care of by the transistor model.

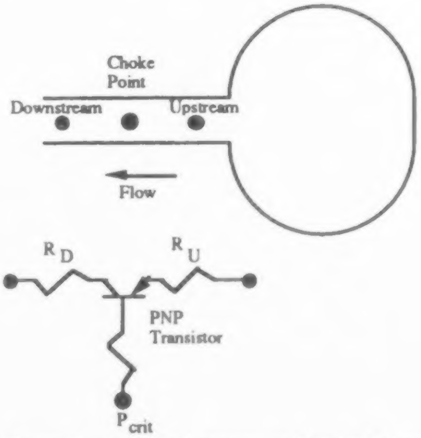


Figure 1. Analogy between collapsible airway and PNP transistor. The choke(collapse) point is set by transluminal pressure and airway compliance.

METHODS

The original model was composed of central airways(trachea and main stem bronchi) and two lung parenchymal compliances. This required a circuit simulation of 3 transistors. Airway compliances were added to all airway segments. Also, chest wall resistance and compliance were added to link pleural pressure to pressure at the body surface. Forced expiration following maximum inspiration was simulated by setting transpulmonary and airway pressures to +30 cm H_2O as an initial condition followed by compression (body surface) or evacuation(mouth) at 40 cm H_2O. The models used for compression and evacuation runs were identical except for the site of pressure application and an additional downstream resistance added during evacuation to account for experimentally observed entrance losses present during evacuation (4). Simulations were run using the PSPICE (MicroSim Corp.) package on an IBM PC compatible computer(Intel 486-2/66). Each run of 10 seconds test time was completed within 5 seconds of compute time.

RESULTS

Expired flow versus time for both compression and evacuation is shown in Figure 2. The individual responses could not be distinguished so only one response is shown. The pressure gradients across the tracheal wall for both cases are compared in Figure 3. Note that a significant difference of up to 35 cm H_2O is observed during the initial 2 seconds. This magnitude of transluminal pressure in the trachea should be associated with a two-fold difference in tracheal diameter and airway flow velocity (2).

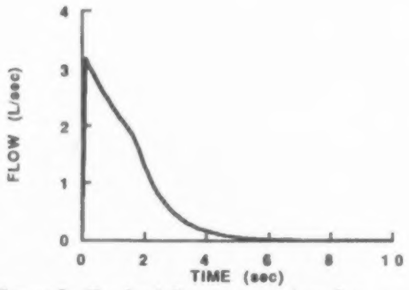


Figure 2. Expired flow versus time for compression and evacuation.

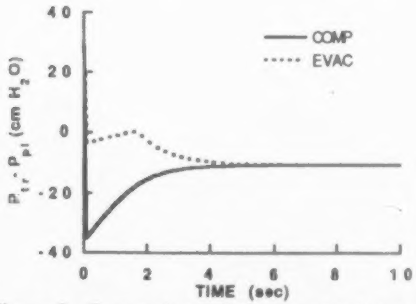


Figure 3. Comparison of trans-tracheal pressures during compression and evacuation at 40 cm H_2O.

DISCUSSION

Effects of compression on the body surface and evacuation from the mouth (also called exsufflation) are felt to yield identical results in the airways (3). Here, identical flow-volume responses were observed, in agreement with this view. However, differences in trans-tracheal pressure gradient were found which had profound implications on tracheal air velocity. This difference is directly related to an extra downstream resistance added during evacuation and not compression. That such a resistive pressure drop exists during evacuation of the trachea has been experimentally established (4). This resistance is connected with tracheal narrowing near the end where the negative pressure is applied. Such narrowing would most likely occur in the extra-thoracic tracheal segment which is surrounded by atmospheric pressure for both maneuvers. For compression, the transluminal pressure difference and resultant constriction at this site only would be negligible in comparison . Since this resistance is downstream of the sites of flow limitation, it has no influence on expired volume and flow, but had a large consequence on thoracic trans-tracheal pressure. Cough assist by thoraco-abdominal compression should then be associated with a higher tracheal airflow velocity within the thorax than assist by evacuation.

REFERENCES

1. Solway, J., J.J. Fredberg, R.H. Ingram, Jr., O.F. Pederson, and J.M. Drazen. J. Appl. Physiol. 62: 2013-2025, 1987.

2. Lambert, R.K., T.A. Wilson, R.A. Hyatt, and J.R. Rodarte. J. Appl. Physiol. 52: 44-56, 1982.

3. Elad, D., R.D. Kamm, and A.H. Shapiro. J. Appl. Physiol. 65: 14-25, 1988.

4. Jones, J.G., R.B. Fraser, and J.A. Nadel. J. Appl. Physiol. 38: 1002-1011, 1975.

ACKNOWLEDGMENTS

The author is indebted to Dr. S.M. Yamashiro for suggesting this problem for simulation and many helpful discussions.

Patsy Kawaoka
9918 N.E. 116TH ST
Kirkland WA, 98034 U.S.A.
(206) 820-6587

A HYBRID INTELLIGENT SYSTEM FOR CLASSIFICATION OF DYSPHAGIA

Narender P. Reddy Ph.D., S. Suryanarayanan, D.F. Prabhu, E.P. Canilang M.D.*
Dept. of Biomed. Engr., University of Akron, Akron OH 44325
***Edwin Shaw Hospital, Akron OH 44312**

Abstract

A major problem in the rehabilitation of dysphagic patients is the identification of subjects at risk of aspiration. Recently, we have developed noninvasive biomechanical measurements to asses the patient, and have developed an expert system to classify the patient at risk of aspiration using these measurements. The purpose of this study is to develop a hybrid intelligent system to classify the patient using these signals. The system has a feature extraction unit with two sets of neural network models and a fuzzy logic system. The individual blocks have been tested on data obtained from a set of normal and dysphagic subjects and compared against the clinician's classification.

Introduction

Dysphagia denotes a swallowing disorder, and presents a major problem in the comprehensive rehabilitation of stroke and head injury patients. Swallowing disorders of the pharyngeal phase often cause aspiration and choking that could lead to death. The current techniques of clinical assessment are qualitative and are based on "feeling", or on video-flurographic examination which exposes the patient to radiation and therefore cannot be conducted on a daily basis. We have recently identified and developed noninvasive methods to measure certain biomecahnical parameters to quantitatively assess the swallow [1-3]. Acceleration and swallow pressure measurements have been obtained from the subject to quantify the pharyngeal phase of swallow. We have found significant differences in these signals obtained from normal and dysphagic subjects and the technique has been clinically evaluated [2-3]. Dysphagic patients often exhibit coughing and there could be number of artifacts like wire kinking present in the acceleration signal. Currently, a trained technician is needed for data analysis and acceleration pattern recognition. In order for the biomechanical technique to be clinically useful, automated techniques are needed for measurement and analysis of the data. The purpose of the present investigation was to develop hybrid intelligent systems for classification of dysphagic patients using the set of biomechanical measurements.

Methodology

A hybrid intelligent system consisting of a feature extraction module, two sets of neural networks , and a fuzzy logic diagnosis system [4] was developed to classify the risk of aspiration of the patient into four categories (a) normal, (b) mild, (c) moderate, and (d) severe . The neural network model I (NNM-I) was developed to distinguish between swallowing and coughing (including other artifacts). If the signal was identified as 'good', then the features were inputted to the second set of networks. The second neural network model (NNM-II) was developed to classify the pattern of swallow as 'normal' or 'mild' or 'moderate' or 'severe'. The fuzzy logic system used the pattern information from NNM-II along with data from acceleration, swallow pressure and the number of attempts to elicit a swallow to classify the patient. Acceleration and swallow pressure were simultaneously measured from a patient. An ultra-miniature accelerometer was placed on the skin of the throat at the level of the thyroid cartilage. To measure swallow pressure a catheter was placed at the base of the tongue and the other end connected to a physiological transducer. In normal individuals a swallow gave rise to a characteristic pattern that was absent , distorted or delayed in dysphagic patients [2]. The signals were amplified, filtered, and A/D converted to store in a computer.

The acceleration signal was sent to the feature extraction system. This system consisted of a high pass digital filter that removed the baseline variations. The signal was segmented and fourier transformed to extract a set of time and frequency domain characteristics. These features were used by NNM-I to classify the signal as a swallow or a cough. The model consisted of a set of networks that differ in the initial weights used. The output of the model was a majority opinion of the individual networks. If the signal was identified as a swallow, the features were inputted to NNM-II. This model also was made of a set of networks. These networks classify the acceleration pattern into one of the four categories. The classification of the acceleration pattern was a majority opinion of these networks and was inputted to the fuzzy logic system.

The fuzzy logic system used a set of four input parameters, peak to peak acceleration, peak to peak swallow pressure, number of attempts to elicit a swallow and the pattern of acceleration signal. Four membership functions (corresponding to the four categories) were defined for acceleration, swallow pressure and the number of attempts. The system fuzzified the input data by calculating memberships values for each of the variables. The membership values were used in a set of IF... THEN... relational rules. The output of the rule base was a set of membership values that were defuzzified using the centroid defuzzifier. The defuzzified output was a continuous variable on a scale of 1-4, where 1 represented severe and 4 represented normal. The system was evaluated using swallow and coughing signals from normal and dysphagic individuals. The system classification was compared against the clinician's classification.

Results

The individual blocks of the system were tested on a set of subjects. Preliminary results indicated that NNM-I distinguished between a swallow and a cough in 100% of the cases. NNM-II classified the pattern correctly in 93% of the cases. The fuzzy logic system accurately classified the subject in 88% of the cases.

Conclusion

A hybrid intelligent system has been developed to classify dysphagic subjects into four categories of risk for aspiration and has been tested on normal and dysphagic subjects. Preliminary results show good correlation between the system classification and the clinician's. However, a study of the integrated system with a larger group of subjects is necessary.

Acknowledgements

This project was supported in part, by a grant from the National Institutes of Health (NIH # 1R15DC01654-01).

References

1. Reddy NP, Costarella BR, Grotz RC. Canilang EP, "Biomechanical Measurements to Characterize the Oral Phase of Dysphagia," *IEEE Trans. in Biomed. Engr.*, **37**: 392:397, 1990.

2. Reddy NP, Canilang EP, Casterline J, Rane MB, Joshi AR, Thomas R, Candadai RS, "Noninvasive Acceleration Measurements to Characterize the Pharyngeal Phase of Swallowing," *J. Biomed. Engr.*, **13**: 379:383, 1991.

3. Reddy NP, Thomas R, Canilang EP, Casterline J, "Towards Classification of Dysphagic Patients using Biomechanical Measurements," *J. of Rehab. Res. and Dev.*, **31**: 335-344, 1994.

4. Suryanarayanan S, Reddy NP, Canilang EP, "Fuzzy Logic Diagnosis System for the Classification of Pharyngeal Dysphagia," *Int. J. of Biomedical-Computing.* (In Press)

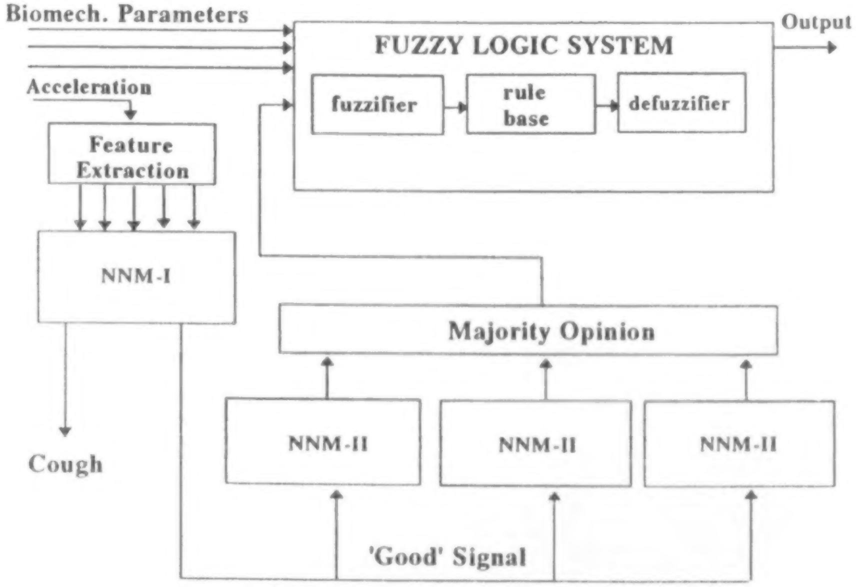


Fig.1 Block Diagram of the Hybrid Intelligent System

Narender P. Reddy, Ph.D.
Professor, Biomedical Engineering
University of Akron, OH 44325-0302
Phone: (216)-972-6653
Fax: (216)-374-8834

A QUANTITATIVE EVALUATION OF UPPER LIMB MOTOR FUNCTION IN CHILDREN WITH PHYSICAL DISABILITIES

Raghavendra S. Rao†; Sundaravalli Sudarsan†; Rami Seliktar††; Pat Benvenuto*
†Institute of Biomedical Engineering and Sciences, Drexel University, Philadelphia, PA
††Professor of Mechanical and Biomedical Engineering, Drexel University, Philadelphia, PA
*United Cerebral Palsy Association of Philadelphia and Vicinity, Philadelphia, PA

ABSTRACT

Quantification of upper limb dysfunction is essential for the evaluation of performance of children with disabilities, in the control of assistive devices. This report discusses the preliminary work done to assess the functional ability of children with and without disabilities, on two generic input devices, the keypad and the force joystick. Two aspects were studied, namely the range of mobility of the upper limbs over a horizontal surface, and the aiming characteristics of a computer based aiming task using a force joystick. Our findings show the existence of distinguishing features which can clearly differentiate between performance of children with different levels of motor impairment due to cerebral palsy, and also from those who are non-disabled. Further efforts aimed at a more complete interpretation of these results are now in progress.

BACKGROUND

Adaptive equipment for children cannot be designed based on performance data obtained from adults. There is need for a database of the physical performance spectra of children, both disabled and non-disabled. Absence of such information hinders effective utilization of the potential of children with motor impairment. With a systematic evaluation protocol, one can determine the best interface that suits a child's unique needs and capabilities.

A few studies have been done to evaluate the motor capabilities of children with disabilities using quantitative methods. McClenaghan et.al. (2) have developed instrumentation to record the temporal and muscular measures for studying upper extremity performance and trunk stability in a three position reaching task. Computer based pre-driving tasks were used by Verburg (7) to determine the predictors of successful control of powered mobility. His results demonstrate a high variability in the scores obtained from children with disabilities. Reddihough et.al.(4), have examined the ability of accelerometry measurements to discriminate normal from abnormal motor control and the repeatability of their technique. Computerized tracking tasks test one's ability to use the joystick as an input device. Stewart (5) suggests the use of the isometric joystick for people beginning to drive a wheelchair though it does not offer any distinct advantage over the displacement joystick. McGill et. al. (3) and Widman et.al. (8), have demonstrated that individuals with cerebral palsy and intention tremor show improvement in tracking tasks with the use of isometric joysticks. Rosen et. al (6) on the other hand, have shown improved tracking with damped joysticks. Behbehani et.al. (1) have evaluated upper extremity performance in healthy individuals and patient populations. These studies indicate that it is possible to objectively measure and quantify physical performance.

OBJECTIVE

The aim of our work is to quantitatively study the performance capabilities of physically challenged children. Our initial objective is to quantify upper limb ability in controlling two basic input devices, the keypad and the force joystick. As the preliminary stage of keypad study, the outreach space of the upper limbs was studied. Currently, a keypad/force plate is being developed for a more customized approach towards individual performance assessment. Ultimately, incorporation of artificial intelligence will facilitate adaptation of keypad resolution and other control features, to suit the individual characteristics of the operator. The joystick has become a common control device to operate environmental appliances and powered mobility aids. At this stage of our study our focus is on the aiming and positioning ability of children with and without disabilities, while performing a computerized targeting task using the force joystick as an input device. The long term goal of our project is to develop a system that determines the most appropriate interface, that conforms to the special needs and abilities of an individual with disabilities.

METHOD

Three schools for children with disabilities were involved in the study. Test subjects were of pre-school age, selected by physical therapists on the basis of 'cognitive motor mismatch' where motor disability is associated with normal cognitive capacity. A few children without physical disabilities acted as a control group. The most common etiology of the motor disabilities was congenital cerebral palsy. Tests were performed in the children's school environment. The area of the range of mobility was mapped using a device semi-annular in shape, with outer and inner diameters of forty one inches and nine inches respectively. The disc was marked by radial lines every ten degrees to form segments numbering from one to eighteen, and by concentric arcs spaced an inch apart, marked alphabetically from A to P. These formed a system of two hundred and eighty eight grids, each characterized alphanumerically. The joystick consisted of a biaxial load cell instrumented with strain gages in a half-bridge configuration, providing two sets of signals, one in the X-direction, and the other in the Y-direction. The strain gage amplifier was connected to a Macintosh via data acquisition board. A computer program was developed to acquire data from the force joystick which controlled movement of an animated cursor in a video game. The displacement of the cursor was programmed to correspond to the magnitude and direction of the force applied. The initial position of the cursor at the center of the screen, corresponded to zero force on the joystick, and extreme positions to five pounds of force. The experiments were conducted in a room free of distractions, with the subject comfortably seated in a chair.

Mapping Outreach Area:
The mapping device was positioned midway between the waist and axilla, supported on either side by two Ablenet switch mounters. The experiment was videotaped and photographed. The child was given an adapted toy operated by a bright colored plate switch. The toy and switch were placed on the tray and the child allowed to get familiarized with its operation. At the start of the experiment, the switch was placed within easy reach of the child. The grid position of the switch at a successful hit, was recorded. The child often started with the use of the dominant limb. By systematically moving the switch around the entire area, grid positions of successful access were recorded. The procedure was repeated with the opposite limb. Each session was limited to ten minutes, to ensure attentiveness and cooperation from the child.

Targeting with Force Joystick:
The joystick was mounted on a table of adjustable height. Prior to data collection, the child was allowed to play with the game and get a feel of the joystick. In each session, the targets appeared successively at four locations on the screen namely, top center (North), bottom center (South), left center (West) and right center (East). After the subject becomes familiar with the procedure, four to five trials were recorded at one sitting. Each trial consisted of reaching the set of four target sites, with the cursor located at the center of the screen.

RESULTS

Mapping Outreach Area

Results of the mappings of outreach area obtained from three subjects are presented here.

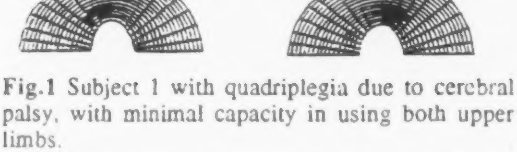


Fig.1 Subject 1 with quadriplegia due to cerebral palsy, with minimal capacity in using both upper limbs.

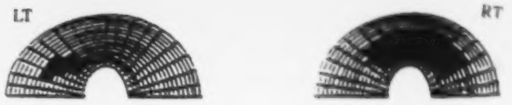


Fig.2 Subject 2, with cerebral palsy, with minimal involvement of the right and moderate involvement of the left upper limbs.

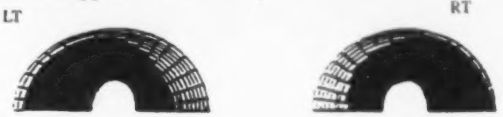
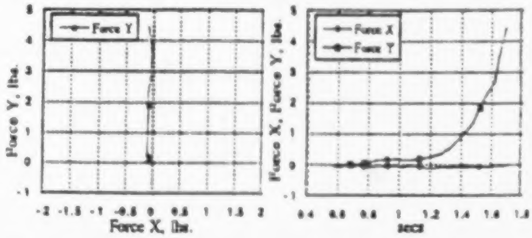


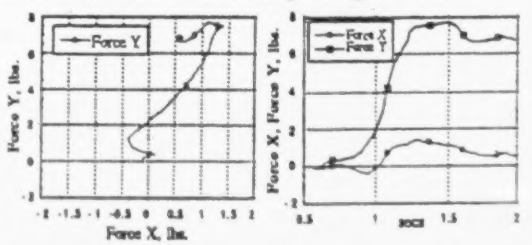
Fig.3 Subject 3, with congenital deformity of both hands, without neuromuscular involvement.

Targeting with Force Joystick

Results of the cursor movement towards a target in the top center (North) position are shown here.



Figs. 4a & 4b show the maximal performance of a non-disabled child while using the right hand.



Figs. 5a & 5b show the performance of a child with spastic quadriplegia, using the right hand.

DISCUSSION

The above studies show the presence of features distinguishing the performance of non-disabled children from children with disabilities, and also between disabilities of different etiology and severity. Further studies and analysis need to be done to characterize these differences objectively.

The study on outreach area mapping shows that with minimal residual functions as in subject 1, there is some area accessible to the child. Subject 3, the child with physical deformities of the hands without any disabilities, has a pattern close to that of individuals with normal reach. Mappings of subject 2 is proportional to the degree of motor involvement in each limb. From the above results it is evident that the pattern of outreach area mapping, differs based on the handicap in each upper limb.

Comparison between the two sets of data in the performance on a joystick illustrates the differences between an able-bodied subject and one with cerebral palsy. Although the results from this preliminary study do not as yet quantify subject performance, the method shows promise in the gathering of objective data. Targeting ability will be studied in a variety of ways namely, the number of maneuvers made in reaching a target, the time taken to reach a target, and the coordination (ability to control the X and Y coordinates simultaneously). With such an analysis, a child's ability to control a mobility device, comprehension of directionality, and ability to generate a proportional command can be studied. Results from the various targets positions will be analyzed in the above manner and a set of objective performance criteria developed.

WORK IN PROGRESS

Currently, a study is underway to look at the area of outreach of the upper limbs using a combined system of a force plate and a video based motion analysis unit. Spatial motion trajectories, force patterns applied by the hand on contact with the pad, and the positioning accuracy are being studied. The temporal difference between the initiation of motion, (target approach phase) and contact with the force plate (target contact phase), will indicate the ease of access. The results obtained from the two recording systems will be studied as a unified measure of 'Reach of the Upper Limbs'.

Data collected from targeting tasks with a force joystick, and the force plate will be used as a knowledge base for performing assessment using statistically based pattern recognition algorithms and expert systems. The parameters extracted from the subject's tracking performance will help in developing an intelligent system that predicts the intention of the operator and improves the task intended.

REFERENCE

(1) Behbehani K., Kondraske G.V., Titner R., Tindall R.A.S., Imrhan S.N., 'Evaluation of Quantitative Measures of Upper Extremity Speed and Coordination in Healthy Persons and in Three Patient Populations', Archives of Physical Medicine and Rehabilitation, Vol.71, 1990, pp 106 - 111

(2) McClenaghan B.A., Bablich K., Sochaniwskyj A., Koheil R., 'Design of Instrumentation to Quantify Upper Extremity Motor Control of Children with Cerebral Palsy', RESNA 9th Annual Conference, Minneapolis Minnesota, 1986, pp 158 - 160

(3) McGill R., O'Beirne H., Milner M., Naumann S., 'Towards the Development of Adaptive User Interfaces for Tremor Disabled Persons: A Blackboard Expert System Approach', Annual International Conference of the IEEE-EMBS, Vol.13 (3), 1991, pp 1262 -1263

(4) Reddihough D., Bach T., Burgess G., Oke L., Hudson I., 'Objective Test of the Quality of Motor Function of Children with Cerebral Palsy: Preliminary Study', Developmental Medicine and Child Neurology, Vol.32 (10), 1990, pp 902 - 909

(5) Rosen M.J., McDowell F., Aisen M., 'The MIT Damped Joystick: A Control Interface for Tremor-Disabled People', Rehabilitation R & D Progress Report (521), 1991 pp 456

(6) Stewart H., Noble G., Seeger B. R., 'Isometric Joystick: A Study of Control by Adolescents and Young Adults with Cerebral Palsy', The Australian Occupational Therapy Journal, Vol.39 (1), 1992, pp 33 - 39

(7) Verburg G. 'Predictors of Successful Powered Mobility'. Proceedings of RESNA First Northwest Regional Conference Seattle, Washington, 1987: pp. 70 - 104

(8) Widman L.M., Cooper R.A., Robertson R.N., Sterr III J.F., Grey T.L., 'Evaluation of an Isometric Joystick for Power Wheelchair Control', RESNA Conference, 1993, pp 364 - 366

ACKNOWLEDGMENT

This work was supported in part by a grant from the Robert Wood Johnson Foundation (RWJ Grant # 19944) and the Calhoun Fellowship of Drexel University. The authors thank the United Cerebral Palsy Association of Philadelphia and Vicinity, the Easter Seal Society of Philadelphia and the HMS School for Children with Cerebral Palsy for their cooperation and help with the project. The guidance from members of the Applied Science and Engineering Laboratories at A.I. duPont Institute is gratefully acknowledged.

Raghavendra S. Rao
Biomedical Engineering and Science Institute
Drexel University
32nd & Chestnut St
Philadelphia PA 19104 U.S.A.
Tel: (215) 895-2376 Fax: (215) 895-1478
E-mail: sg93b4st@dunx1.ocs.drexel.edu

IDENTIFYING ESSENTIAL FUNCTIONS: AN ADDITIVE VALUE FUNCTION

Don Malzahn
Department of Industrial and Manufacturing Engineering
Wichita Rehabilitation Engineering and Research Center
Wichita State University, Wichita, KS

ABSTRACT

Appropriately developed job descriptions are commonly assumed to be the basis for identifying the "essential functions" of a job. Few organizations have job descriptions developed for this specific purpose. A consistent method of expressing the "importance" of task elements may be a more effective method for firms to identify essential functions. A simple additive value function is shown to be a sufficient model for determining the relevant importance or "essentiality" of job functions.

BACKGROUND

The definition of the essential functions of a task is the first step in determining whether components of a task are eligible for elimination from a specific job to be performed by an employee with a disability. In the vast majority of situations the essential components of a task are obvious to all parties, either through a well-defined job description or through a consensus of employees and management. Much of the popular literature regarding ADA implementation suggests that job descriptions provide a simple and direct means of identifying and documenting the essential functions of a task (1, 2).

Formal job descriptions, as they exist in most organizations, are not an effective means of identifying the essential functions of a task. Although they are assumed to provide the information that serves as the foundation for organizational planning and design, human resource management, and other managerial functions, most job descriptions are out of date and have not been revised as tasks evolve over time. Job descriptions are also used for a variety of purposes, such as, allocation of functions, person specification, job organization, task interface design, skill acquisition, and performance assurance. These uses may not be compatible with identifying the essential functions. The textbook approach to identifying essential functions through well written and current job descriptions is difficult for most organizations to realize. There may be a more direct and consistent process for identifying essential functions.

PROBLEM STATEMENT

There is a legal requirement that an employer identify the essential functions of a task under the ADA that may be important in the case of a law suit. If insuring a legal defense is the only reason for identifying essential functions, then the potential benefits of the effort are small. Many firms are examining the nature of the work performed in order to increase the effectiveness of the organization. There are several related approaches; continuous improvement, business process re-engineering, and team based management. Underlying themes in all these are the identification of activities that do not add value to the product or service, and activities that are "bottlenecks" where there is limited capacity or flexibility. Activities that do not add value are targets for elimination and activities that are bottlenecks are targets for re-engineering or cross training.

From management's perspective it, may be useful to develop a means of scoring a task in terms of its degree of essentiality or importance. For example, which functions should be listed in a job description, advertisement, or posting? When deciding among job candidates, which task functions should carry more weight? Again, in most situations, important functions are obvious to all involved. There may be situations where, because of the task complexity, these determinations are more difficult.

The legal finding of whether a particular function is essential is a factual determination that must be made on a case by case basis. In concluding whether a particular function is essential, all relevant evidence will be considered. A history of the consistent application of a rational process of identifying essential functions is obviously part of this evidence. From Title I of the ADA --"For the purposes of this title, consideration shall be given to the employer's judgment about what functions of a job are essential, and if an employer has prepared a written description before advertising or interviewing applicants for the job, this description shall be considered evidence of the essential functions of the job." Thus it is the employer's judgement that defines essential functions and the written job description is but one form of evidence of this judgement.

APPROACH

ESSENTIAL FUNCTIONS

From a business perspective, the term "essential" implies that the function *must* be performed if the organization is to reach its object. Essential is an absolute term, either a function is essential or non essential. From an employer's perspective a more useful concept may be the importance of a task function. Importance may be measured along a continuum with some functions being more important that others. If we assume that we can measure the importance of a function, then its measure requires multiple attributes. These same factors may be used as the attributes for measuring the relative importance of a function in a task.

Attributes

The basic requirements are the definition of the attributes of a task function that can be used to measure the quality "essentialness" and a means for combining attributes into a single measure. The basic set of characteristics required of a set of attributes are:

Completeness. Include all factors considered in the decision process.
Importance. Attribute should have an effect on preference.
Measurability. Capable of being objectively or subjectively quantified.
Familiarity. Should be understandable.
Nonredundancy. No two attributes should measure the same criterion.
Independence. Within limits, changes in on attribute should not change other attributes. (3)

There is no shortage of suggestions for factors to consider in Identifying essential functions or "fundamental duties." Much has been written about and much can be derived from regulations and past practices of EEOC, the Office of Federal Contract Compliance and ADA.

The following list of factors was compiled from a variety of sources and was grouped into four broad areas.

Value added
- Does the position exist to perform that function?
- What is the employer's judgment about which functions are essential?
- What is the relative importance of this function compared to others in the job?
- What are the consequences of not performing the function?

Legal requirements
- Is the function required by a collective bargaining agreement?
- Is the function part of a written job description?

Uniqueness
- How many other employees are available to perform function?
- What degree of expertise is required to perform the function?
- What is the level of work experience of incumbents in the job?
- Are there peak work periods that would prevent the transfer of to others?

Time involvement
- What is the proportion of time used in performing the function?

These basic factors can be defined in terms of four broad attributes of a task function.

Value Added. (VA) The value added to the product or service.
- Degree to which existence of position is dependent on function.

Legal. Restrictions. (LR) Legal or ethical restrictions.
- Degree to which function is required by law or collective bargaining agreement.

Uniqueness. (UN) Availability of function in organization.
- Degree to which capacity to perform function is not available to meet requirements.

Time. (TI) Time involved in function
- Portion of position time spent in function

These four attributes incorporate the factors mentioned in the literature as affecting the definition of essential functions (1, 2). Each of these attributes may have several lower level attributes used to define them. The set of four higher level attributes meets the requirements for a valid preference structure except the ***time involved in function*** attribute. This attribute does not meet the ***importance*** characteristic. Even if a function scored low on ***value added***, ***legal restrictions***, and ***uniqueness*** but scored high on ***time*** it, would not be more essential. If it takes a long time, many people can perform it, there are no legal restrictions, and it adds no value, then from a business perspective it is definitely not essential. Although time is the most easily measured attribute, it does not provide information relevant to the organization in determining the importance of a function.

Model Form

Can the four factors listed above determine the relative importance of a function in a task or position? Can they be combined simply to measure the relative importance? . Does a multiple attribute value function provide a means for making this determination? The simplest form of a value function is an additive value function. In order for an additive value function to be able to describe the values a condition of *preferential independence* must hold between the attributes.

"The pair of attributes *X* and *Y* is ***preferentially independent*** of *Z* if the conditional preferences in the *(x, y)* space given z' do not depend on z''" (3). In this situation this means that the following conditions must hold:

$$(VA\uparrow, LR\downarrow, UN\downarrow) > (VA\downarrow, LR\downarrow, UN\downarrow)$$

and

$$(VA\uparrow, LR\uparrow, UN\downarrow) > (VA\downarrow, LR\uparrow, UN\downarrow)$$

In other words, when Legal Restrictions (LR) and Uniqueness (UN) are low then the function with the highest Value Added (VA) is more important. The preference for the function with higher VA holds even if the level of LR is changed to a higher level. By examining all combinations of attributes and verifying that this condition holds, we can assume that the attributes are preferentially independent. If preferential independence holds, then a simple additive function can be used to estimate relative importance.

$$v(VA, LR, UN) = v_{VA}(VA) + v_{LR}(LR) + v_{un}(UN)$$

where:

(VA), (LR), *and* (UN) are scores of a function on each attribute

v_{VA}, v_{LR}, *and* v_{LR} are the relative importance of each attribute

Is it reasonable to measure these attributes and their relative importance? There are many techniques available for developing measures of the relative importance of attributes (3, 4, 5). An approach such as Satty's AHP (4) may be used to determine the importance of the attributes through a process of pairwize comparisons. This approach has received considerable attention in industry. It has been used to quantify subjective perceptions of importance in a variety of applications.

IMPLICATIONS

It is feasible to develop a simple function that provides an estimate of the degree of essentialness attributed to functions within a task. The approach is based upon the assessment by the enterprise of the relative importance of the factors Value Added, Legal Restrictions, and Uniqueness in valuing task elements. There is no method of determining whether a function is in fact essential or not, but functions can be ordered as to importance or essentialness. This approach does not relieve the organization of the responsibility of determining which task functions are essential. It does provide a direct, consistent, and rational method of identifying essential functions.

REFERENCES

1. Chalker, Matt. (1991). "Tooling Up for the ADA." HR Magazine, December 1991, pp 61-65.

2. Kearney, Deborah. (1994) Reasonable Accommodations. New York: Van Nostrand Reinhold.

3. Keeney, Ralph, and Howard Raiffa. (1976) Decisions with Multiple Objectives: Preferences and Value Tradeoffs. New York: John Wiley & Sons.

4. Saaty, Thomas. (1980). The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. New York: McGraw-Hill.

5. von Winterfeldt, D., and W. Edwards (1982). Decision Analysis and Behavioral Research. Cambridge: Cambridge University Press.

ACKNOWLEDGMENTS

Funding for this project was provided by the National Institute on Disability Rehabilitation Research (grant number (H133E30027).

Don Malzahn
Industrial & Manufacturing Department
Wichita State University
Wichita, KS 67260-0035
(316) 689-3425
malzahn@ie.twsu.edu

RISK FACTORS FOR FUTURE DISABILITY DUE TO LOW BACK INJURIES

Larry D. Haugh, Rowland G. Hazard, Sheila Reid, Jeffrey Preble
Vermont Rehabilitation Engineering Research Center for Low Back Pain
University of Vermont
Burlington, VT

ABSTRACT

A short, easily administered and scored questionnaire has been developed for disability risk assessment. The selection of 11 scorable items was based on a 3 month follow-up study of 163 low back pain injured workers, with the questionnaire given within 15 days of their work related injury. These 11 items were individually most predictive of failure to return to work as measured by Kappa.

BACKGROUND

Our Rehabilitation Engineering Research Center has had a longstanding research interest in developing better predictors of disability due to low back pain. Back symptoms are the most common cause of disability for persons under age 45 and back injuries represent the second most common cause of work absence. The effect on costs to society is in the tens of billions of dollars, since 42% of compensable costs are accounted for by back injuries. Much of this cost is due to workers unable to return to work on a long term basis. It is critical that treatment and workplace interventions be timed to return the worker to the workplace as soon as appropriately possible. Since the typical injury is acute, it is important to be able to identify as early as possible in the clinical process of care that smaller percentage of workers who are at greater risk for long term disability. As a consequence they can receive the necessary attention and possibly an enhanced treatment strategy.

Our earlier research efforts focused on reviews of the literature and a national expert consensus panel to develop a bank of questionnaire items that could be asked of low back pain patients upon first admission to a clinic. The expert panel also helped develop scoring rules and weights that could be attached to such items. The resulting patient questionnaire and scoring system was validated on several cohorts of patients at different clinics nationally. The questionnaire that was ultimately developed utilized 46 items for those patients having a job at the time of clinic visit, although only 33 were actually used in the scoring needed to calculate an overall risk score for disability at 3 or 6 months follow-up after clinic visit. The risk score also utilized responses obtained from a short physician's form.

RESEARCH QUESTIONS

The patients previously studied had had low back pain typically for several months prior to their clinic visit, so that there was no direct information available on predictive value of the questionnaire for patients seen immediately after injury. Also it was hoped that the more complicated scoring algorithm of the predictive instrument could be simplified for hand scoring in the clinic, since a computer program was required for scoring of the questionnaire results.

Which risk factors are most predictive of eventual disability 3 months later for that group of patients seen within a few weeks of their low back injury?

Could a shorter questionnaire be developed so that completion time in a primary caregiver's office can be as short as possible?

Could a very simple scoring rule be developed so that quick hand scoring can be accomplished simultaneously in the clinic office?

METHOD

A collaborative agreement was established with the State Department of Labor and Industry so that we could contact all workers having low back pain injuries reported within 2 weeks of their date of injury. After obtaining consent by phone, such patients were mailed a questionnaire to be completed on their own and returned to us. They were also followed up at 3 months after injury by phone to determine whether they were disabled (unable to work) due to low back pain.

RISK FACTORS FOR DISABILITY

A total of 33 items were selected for the questionnaire from the previously developed RERC form and from results for another national expert panel that had been solicited for items and risk factors important in Worker Capacity Evaluation.

Each of the questionnaire items was considered as a measure of a potential risk factor for long term disability. Many of the items had a measurement scale which was not dichotomous in nature. However for simplification of clinic scoring all items were investigated as to how to best divide their possible responses into two categories: predictive of disability or predictive of return to work. Item responses felt to be predictive of disability were scored as a 1, while item responses felt to be predictive of return to work were scored as a 0. The predictive value of each dichotomously scored item was validated with the actual disability status at 3 month follow-up through calculation of a Kappa value. Kappa provides a chance-corrected measure of the agreement between predicted disability and actual disability, with 1 corresponding to perfect agreement.

Those individual items achieving a Kappa of at least 0.10 were selected for inclusion in a newly designed questionnaire for disability risk assessment.

RESULTS

In total, 699 injured workers were contacted to request consent for participation, but 37% (257) did not consent. Of the 442 consenting, 48% (211) returned the questionnaire. Less than 2% (4) of the subjects were lost to 3 month follow-up. Of those followed-up, we selected only those who had completed the form within 15 days of injury.

A total of 163 injured workers completed their questionnaire within 15 days of their date of injury, and were successfully followed up at 3 months. Overall, 10% of these were disabled at 3 months due to their low back pain.

A list of the 33 individual questions asked, in an abbreviated form, are given in the table included here. They have been ordered by the size of their Kappa values. As seen there were 11 items having Kappa at least .10 in size.

Abbreviated Question	Kappa
1. Pain in your back right now	.36
2. Expected trouble sitting/standing in job in 6 weeks	.32
3. How well get along with co-workers	.29
4. Certainty will be working in 6 months	.24
5. Doctor visits for back problems	.23
6. Had surgery for low back pain	.20
7. Hospitalization for low back pain	.18
8. Number of times married	.16
9. Ever had back problems before	.14
10. Who to blame for back problem	.11
11. Physical demands of job	.10
12. Severity of worst low back problem	.09
13. Schooling completed	.08
14. Enjoyment of job's working environment	.08
15. Marital status	.07
16. Family member ever chronically disabled	.06
17. How long at present job	.05
18. Financial compensation for LBP ever received	.03
19. Past work absences due to low back pain	.03
20. How paid (salary/wage/commission)	.02
21. Satisfaction with job responsibility	.02
22. How interesting is job	.02
23. Mental demands of job	.02
24. Expected satisfaction when return to job	.02
25. How often exercise/work vigorously	.01
26. Stress with job responsibility	.01
27. Self-employed or not	.00
28. What is best financially (work/compensation)	-.01
29. How interesting is job	-.02
30. Past visits to other health professionals	-.06
31. Ever contacted lawyer for health problem	-.07
32. How long at previous job	-.07
33. How much normally work (part-time/full-time)	-.09

RISK FACTORS FOR DISABILITY

The items with highest predictive value would identify the most important risk factors among these items to be related to

Current pain (1)
Expected ability to do job (2,11)
Co-workers interactions (3)
Self-confidence (4)
History of low back pain (5,6,7,9)
Marriage history (8)
Blame for cause of pain (10)

Of interest in our research development, 3 of these 11 items were not used in the previously developed questionnaire (2,5,9).

DISCUSSION

The 11 items with highest individual Kappas have been selected for use in a future intervention study with the same population of low back pain injured workers. They will be used to screen such workers for those with the highest risk of future disability. A randomized intervention study can then be conducted on those patients with potentially the highest impact on the societal cost of low back pain.

The calculation of total risk score from the selected 11 items is easy because each item contributes a score like 0 or 1 to the total. Even greater weights may be attached to some items based on multivariate logistic regression analyses also conducted. Such weighting can significantly improve the overall predictive value of the questionnaire.

It is of course important to realize that there are potential biases in the predictive validity, due to the large number of nonconsenters and nonreturners. Contrast of these groups with returners can at least characterize the demographic differences between them.

Also, it will be important to continue this research for identifying risk factors, as there will be some differences expected when applied to other cohorts and even the 163 studied here is not comfortably large when so many potential factors are being selected on a statistical basis.

ACKNOWLEDGEMENTS

This research was supported by the National Institute on Disability and Rehabilitation Research (grant H133E30014).

Statistical analysis by Mike Wickenden is greatly appreciated.

Larry D. Haugh
Professor and Director
Statistics Program
University of Vermont
16 Colchester Avenue
Burlington, VT 05401-1455
(802) 656-4350

GAIT ACTIVITY MONITOR FOR LONG-TERM MEASUREMENT OF AMBULATORY FUNCTION

Kim L. ColemaNesset MS, Douglas G. Smith MD, Aaron W. Joseph MS, David A. Boone CP
Prosthetics Research Study — Seattle, WA USA
George Macomber, PhD — Seawell Microsystems, Inc. — Seattle, WA USA

ABSTRACT

In many areas of medicine and research, levels and patterns of daily ambulation are useful indicators of a patient's condition. Long-term, objective monitoring of gait activity can provide valuable information regarding a patient's real-world functionality. We have developed a small, self-contained device which is worn on the ankle and records step counts accumulated during short, successive time intervals. The device is easy to use, requires no intervention by the wearer, and can be set to continuously monitor a patient for up to one month. Following the monitoring period, data are optically downloaded to a computer for analysis. Detailed activity profiles can be generated which reflect habitual patterns of activity, peak performances, patterns of rest, and other gait/activity-related characteristics. Such information can be used alone or in conjunction with more complex laboratory or clinical measurements as a basis for functional level assessment.

BACKGROUND

The assessment of a patient's functional level and the efficacy of prescribed treatment is a continual challenge for researchers and medical caregivers. As the demand for accountability increases, improved tools for assessment are needed. Tools which facilitate objective evaluation are also important for improving rehabilitation programs and the design of prosthetic and orthotic devices (3, 2).

Prosthetic, orthotic and medical evaluations have traditionally been limited to clinical tests, observations by medical providers and self-reporting by patients. The common characteristic of each of these methods is that numerous variables are measured and recorded over a short period of time in a clinic or laboratory. Consequently, such appraisals are susceptible to bias arising from differences between a patient's appearance or condition at the time of evaluation and their longer-term, real-world condition. Factors such as short-term performance behavior, inaccurate or "today-centered" reporting by the patient, and the inherent subjectivity of clinical assessment commonly reduce the accuracy of functional level evaluations. Additionally, for large studies, clinical observations and questionnaire-interview methods of evaluation are time consuming and expensive (12).

STATEMENT OF THE PROBLEM

An alternative and complementary approach to the problem of functional level assessment is continuous, long-term monitoring of patients performing normal daily activities (4). A practical device to achieve this must fulfill several criteria. It must be small, unobtrusive, inexpensive, require little maintenance, have a low power requirement, be waterproof, and be simple for a clinician to operate. Additionally, a trade-off must be made between the duration of the continuous monitoring period and the sophistication of the recorded measurement. A device that fulfills these requirements can assist clinicians and researchers in the evaluation of a patient's functional level and the assessment of treatment efficacy.

For many patients, level of gait activity is a real-world indicator of medical condition. Long-term monitoring of gait has been repeatedly proposed as a means of obtaining meaningful, quantitative measures related to an individual's medical condition and/or physical functionality (5, 6, 7, 8, 10, 11). A number of devices to measure gait-related activity are currently marketed and used for research and clinical evaluation. These include the Caltrac® Personal Activity Computer which increments a measure related to movement intensity (12), the Large Scale Integrated Activity Monitor (LSI) which accumulates a count of movement events and a variety of simple pedometers (1). Such devices, however, do not provide a time-based breakdown of data to reflect activity patterns as well as measures of overall activity.

DESIGN/DEVELOPMENT

We have developed a small, self-contained, waterproof device which attaches to a patient's ankle and continuously records step counts for up to one month (Figure 1). It attaches comfortably to the ankle with a broad elastic strap fastened to the curved, padded inner surface of the case. It neither requires nor allows intervention or adjustment by the wearer.

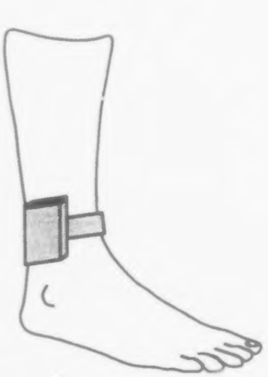


Figure 1: Typical placement of GAM

Unlike simple pedometers which accumulate a single total step count, this electronic gait activity monitor (GAM) stores the number of steps accumulated during each successive time interval to provide a detailed profile of activity (Figure 2). The time intervals can be adjusted between 10 seconds and 2.5 minutes. The accuracy of the programmable sensor exceeds 95% for most types of gait.

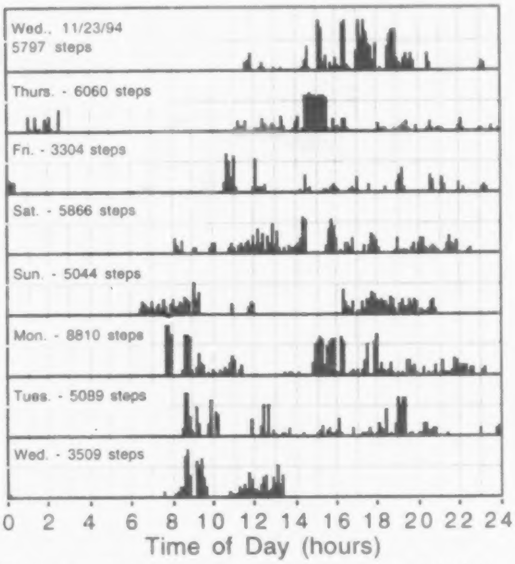


Figure 2: Weekly Step Profile. Each vertical division is 50 steps. Data is displayed in 2.5 minute intervals.

When monitoring is complete the data are optically downloaded to a computer via a wireless interface for analysis. We have identified a set of variables and graphic displays which describe activity profiles in detail. These include indicators of short burst activity and longer endurance activity as well as measurements of overall activity and inactivity patterns. Analysis can provide many useful measurements including:

1) a daily/weekly activity profiles (Figure 2)
2) percent of time spent at different activity levels (Figure 3)
3) preferred step cadences
4) peak performance indicators (Figure 4)
5) duration of continuous activity
6) duration and patterns of rest
7) gait cost of specific activities (Figure 5)

ACTIVITY LEVEL CATEGORIES

Low = 1 - 20 Steps/Minute
Moderate = 20 - 40 Steps/Minute
High = 41 + Steps/Minute

	% Total Time	% Active Time
Inactivity	69.62	
Low Activity	24.13	79.43
Moderate Activity	1.74	5.71
High Activity	4.51	14.86

Figure 3: Activity Level Analysis for 24-hour monitoring period.

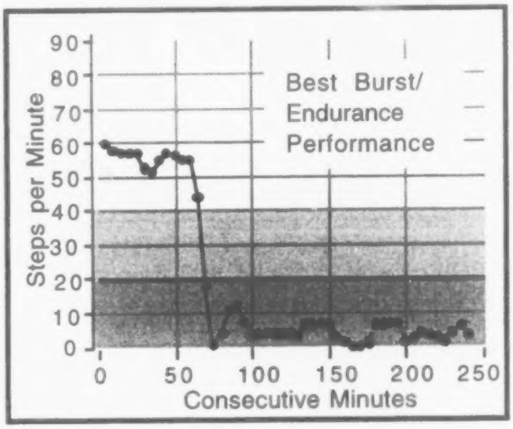


Figure 4: Best Performance Analysis plot is the derivative (ordinate) of a function representing the highest step count achieved during the day within any time block of each duration on the abscissa.

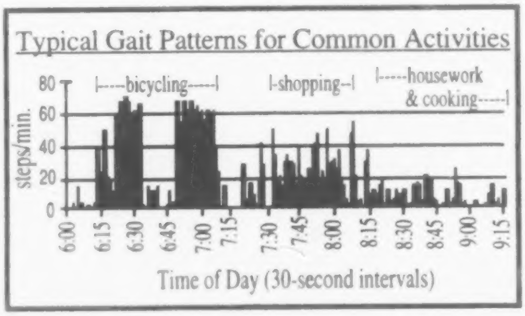


Figure 5: Typical gait patterns for common activities

BEST COPY AVAILABLE

DISCUSSION/EVALUATION

Step count profiles and derivative variables represent a simple, useful approach to functional level assessment. These measures do not replace more complex laboratory analyses which provide detailed information about an individual's short-term condition and performance while being observed/tested. Long-term, unobtrusive monitoring, on the other hand, provides a means of assessing the activity actually undertaken by an individual in the course of normal daily life. Considerable insight can be gained by using a combination of these two approaches. For example, peak capacity can be assessed in the laboratory and compared to peak performance sustained during real-world activities.

Comparing results of consecutive days and weeks provides insight into the relationship between the activity at one time to the activity subsequently undertaken. This can foster a deeper understanding of an individual's best tolerated activity level for sustained health. We believe the GAM can serve as a standard tool for the evaluation of locomotor functionality. Modified versions of the GAM can be used to monitor motion of other parts of the body such as the back, the arm, and the shoulder.

We realize there are some limitations in the interpretation of such measurements. Although related, step counts do not directly reflect energy output or effort. For example, walking uphill, downhill, or while carrying a load can produce an inverse relationship between changes in step rate and energy expended. For most people, however, such conditions do not represent a large portion of gait activity; and any temporary impact on energy requirements would be minor from the perspective of daily or weekly step count profiles. Furthermore, for many applications, mobility is the issue of interest rather than energy expenditure. For example, the comfort, ease of use, and even the appearance of a prosthesis can influence a patient's willingness to walk and thus determine their actual mobility. Step counting is an effective means of measuring ambulatory mobility.

Caution must also be taken when comparing before and after step count data in the evaluation of treatment efficacy. For example, a change in prosthetic components might increase a patient's step length thereby decreasing the number of steps needed to perform a given activity (9) or vise versa (2). A prosthetic alteration which increases a patient's comfort and functionality, however, is also apt to encourage gait activity of increased duration and intensity. In such cases, the gain in functional level can be observed through step count profiles.

REFERENCES

1. Balogun JA, Amusa LO, Onyewadume IU. Factors affecting Caltrac® and Calcount® accelerometer output. Phys Ther 1988:68(10)1500-1504.
2. Chen PW, Cheng CK, Shang HC, Wu JJ. Gait analysis after total knee replacement for degenerative arthritis. J Formosan Med Assoc 1991:90:160-166.
3. Day HJB. The assessment and description of amputee activity. Pros Orth Int 1981:5:23-28.
4. Halstead LS. Longitudinal unobtrusive measurements in rehabilitation. Arch Phys Med Rehabil 1976:57:198-193.
5. Holden JM, Fernie GR. Extent of artificial limb use following rehabilitation. J Orthop Res 1987: 5:562-568.
6. Holden JM, Fernie GR, Soto M. An assessment of a system to monitor the activity of patients in a rehabilitation programme. Pros Orth Int 1979:3: 99-102.
7. Klesges LM, Klesges RC. The assessment of children's physical activity: a comparison of methods. Med Sci Sports Exerc 1987:19(5)511-515.
8. Northfield MR, Schmalzried TP, Belcher G, Amstutz HC. Quantitative assessment of activity in joint replacement patients. 40th Annual Meeting, Orthop Res Soc, Feb. 1994, New Orleans, LA.
9. Powers CM, Toburn L, Perry J, Ayyappa E. Influence of prosthetic foot design on sound limb loading in adults with unilateral below-knee amputations. Arch Phys Med Rehabil 1994:75: 825-829.
10. Sallis JF, Buono MJ, Roby JJ, Carlson D, Nelson JA. The Caltrac accelerometer as a physical activity monitor for school-age children. Med Sci Sports Exerc 1990:22(5)698-703.
11. Washburn RA, LaPorte RE. Assessment of walking behavior: Effect of speed and monitor position on two objective physical activity monitors. Res Q Exerc Sport 1988:59(1)83-85.
12. Wong TC, Webster JG, Montoye HJ, Washburn R. Portable Accelerometer Device for Measuring Human Energy Expenditure. IEEE Transactions on Biomedical Engineering 1981:BME-28(6)467-471.

ACKNOWLEDGMENTS

Funding provided by Department of Veterans Affairs Rehabilitation Research and Development Service, Prosthetics Outreach Foundation, and University of Washington, Orthopaedics Department.

Kim ColemaNesset
Research Engineer
Prosthetics Research Study
720 Broadway, 3rd Floor
Seattle, WA 98122 USA
(206) 328-3116; FAX: 325-3607

A BONDING TECHNIQUE FOR STRAIN GAGE ATTACHMENT ON POLYPROPYLENE ORTHOSIS

Taiming Chu, and Alan N. Gent
Department of Mechanical Engineering and Biomedical Program, New Jersey Institute of Technology
Department of Research, Kessler Institute for Rehabilitation, Inc.

ABSTRACT

In the area of medical and rehabilitation engineering, many assistive devices are made of inert plastics, often polypropylene. For example, the Ankle-Foot Orthosis (AFO) is an external assistive device used by patients who have suffered a stroke. This device prevents or constrains abnormal foot motions. The designer needs to analyze stress which can develop in the orthosis during use. This data is essential for failure modes analysis and in the prediction of fatigue life. Therefore, experimental determination of the stress/strain response is needed. This paper discusses a novel technique which allows the adhesive attachment of strain gages on polypropylene surfaces which are normally not amenable to bonding due to their low surface energy and inert characteristics.

BACKGROUND

Pathological motion of the ankle-foot complex presents a major problem in the rehabilitation of stroke patients (1). They often develop drop-foot, a problem involving excessive and uncontrolled plantar flexion, that affect a person's ability to walk. More specific, drop-foot is characterized by excessive and uncontrolled Achilles tendon force and excessive plantar flexion often leading to toe drag during the stance phase of the gait (1). The AFO is designed to constrain and inhibit this abnormal motion.

In current clinical applications, the AFOs are generally made from a variety of thermoplastic materials like polypropylene, and are custom fitted to the patient. However, this fitting process is based on trial and error procedures (1). Problem of AFO break down due to fatigue is significant because of lack of knowledge of the stress distribution in the AFO. Therefore, experimental determination of the stress/strain response is needed in order to minimize failure and attempt to predict fatigue life.

In general, an experimental determination of stress response of a material is to bond wire strain gages onto the material. Normally, ruffle the surface of the material with abrasive paper. Next, apply cyanoacrylate "Super Glue^{TM}" to bond strain gages on the material surface. Then, strain information can then be collected through the strain gage. However, in the present study, because of the inertness of polypropylene and its low surface energy, standard techniques of bonding strain gages were found to be unsuccessful. The objective of this paper is to describe a new method that has been found recently suitable for obtaining reliable bonding between conventional strain gages and a polypropylene AFO.

METHOD

Previous work on polypropylene and other relatively inert plastics has shown that adhesion is dramatically increased by surface modification including plasma treatment, UV exposure and in some instances exposure to ozone (2 and 3). These techniques introduce reactive sites, for example OH and COOH groups that enhance adhesion (2). A simple procedure is described here for bonding conventional wire strain gages to polypropylene objects, namely the AFO.

First, a plastic welding method was applied. That is polypropylene was partially melted and the gages were embedded under a thin film of polypropylene melted on top of them. This approach, however, did not secure the strain gages to the polypropylene adequately. Errors were found in balancing the strain gage bridge and drift was excessive. Occasionally air gaps could be seen. Thus, this method cannot be relied on for good bonding.

In order to achieve good bonding, the surface of polypropylene must be modified to permit interaction with an adhesive. Polypropylene is known to undergo chemical changes during oxidative aging that lead to the addition of OH and COOH groups (3). The sample was therefore exposed to UV light in an air atmosphere to initiate surface oxidation . First, the areas where strain gages were to be mounted were roughened with abrasive paper. Then the polypropylene was placed at a distance of about 25 mm from a UV light (Model No. UVG-54) for a period of 20-30 minutes. Then the areas to be bonded were wiped with an acetone-soaked cloth. Strain gages were then attached using a cyanoacrylate "Super Glue™". Good adhesion was obtained in this way. The reason for the success in this bonding method is that ozone generated by the UV irradiation or direct free-radical reactions induced in the surface of the polypropylene led to rapid oxidation of the surface and the introduction of oxygen-containing groups that promote adhesion. Terminal strips were also bonded to the polypropylene surface in the same manner.

RESULTS

The above described bonding technique gave strong adhesion of the strain gages. No problems were encountered with de-bonding or mechanical drift. The full data collection system was consist of six strain gage bridges, a multiplexed circuit, an amplifier, a computer, and computer software (Fig. 1). The system was tested. However, only four of the strain gage bridges were operating as expected. Therefore, data was collected based on these four gages. The AFO was strapped to the leg of a normal subject who under instruction subjected the AFO to a variety of dynamic loading conditions (Fig. 2). These included: slow walk, fast walk forward, fast walk backward, jump, putting a known force (80 lbs) on the AFO, and dorsiflexion. Three frames of data (three trials) were conducted for each of these loading conditions. Before the start of each frame, all the four bridges were zeroed using the trim potentiometer on each bridge. After this, the subject was asked to perform the necessary loading task. A sample of data give below (Fig. 3; Forward Slow Walk, Trail # 1).

Fig. 2 A normal subject who under instruction subjected the AFO to a variety of dynamic loading conditions.

Fig. 1 The full data collection system.

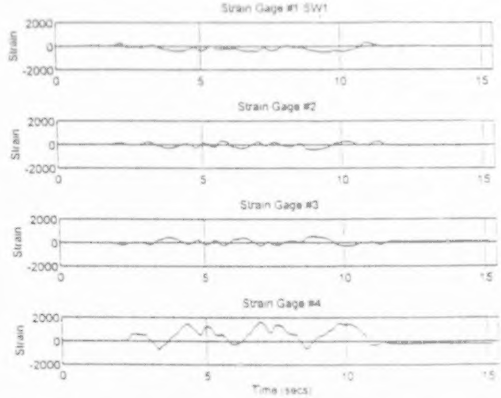


Fig. 3 Strain information in AFO during forward slow walk, Trial # 1.

CONCLUSION

Based on testing results, it was concluded that

1. The strain gage mounting technique based on the UV light treatment of Polypropylene surface was used successfully to instrument the AFO.
2. Reliable bonding between the strain gages and Polypropylene AFO was achieved when the surface is initially treated with UV light.
3. The instrumentation developed for the purpose successfully enabled the simultaneous recording of strains at different locations on the AFO.
4. This study successfully proved the feasibility of providing experimental validation to earlier theoretical findings (1).

REFERENCE

1. T. Chu, N.P. Reddy, and J. Padovan, "Three Dimensional Finite Element Stress Analysis of the Polypropylene Ankle-Foot Orthosis", Advances in Bioengineering (editor: Bidez, M.W.), ASME, N.Y., BED-Vol. 22, pp. 407-409, 1992.
2. D. Briggs, "XPS Studies of Polymer surface Modifications and Adhesion Mechanisms", J. Adhesion, Vol. 13, pp. 287-301, 1982.
3. E. Uchida, Y. Uyama, and Y. Ikada, "A Novel Method for Graft Polymerization onto Poly (ethylene Terephthalate) Film Surface by UV Irradiation without Degassing", J. Appl. Poly. Sci., Vol. 41, pp. 677-687, 1990.

ACKNOWLEDGMENTS

Finding for this project was provided by New Jersey Institute of Technology (SBR 421570).

Thanks to Drs. S. Kesavan, N.P. Reddy, and Mr. S. Sukthankar for their valuable contributions to the project.

Taiming Chu, Ph.D.
Assistant Professor
Dept. of Mechanical Engineering
New Jersey Institute of Technology
University Heights
Newark, NJ 07102-1982 U.S.A
(201) 596-3339

A COMPLIANCE-INDEPENDENT PRESSURE TRANSDUCER FOR BIOMEDICAL DEVICE/TISSUE INTERFACES

Nancy J. Paris-Seeley, Douglas P. Romilly, James A. McEwen*
Department of Mechanical Engineering, University of British Columbia,
*MDDC Medical Device Development Centre, Vancouver, B.C., Canada

ABSTRACT

The measurement of pressure at a device/tissue interface is desirable in many rehabilitation and biomedical engineering applications such as wheelchair seating or mammography in order to optimize the design or performance of the device. Testing of a selection of existing interface transducers has demonstrated that many are dependent on device and tissue compliance. Such a transducer is only useful in an application where it has been calibrated for specific device/tissue compliance combinations. To overcome this limitation the authors have developed an interface pressure transducer whose output signal is not affected by changes in interface compliance. This enables the transducer to quantitatively measure pressure in many applications without the need to calibrate the transducer for varying compliance conditions.

BACKGROUND

Many biomedical applications involve the application of pressure from a biomedical device to a body part or from a body part to a support structure. Examples of the former include mammography, surgical retraction, and tourniquet applications. Examples of the latter include prosthetic sockets, wheelchairs, and mattresses. In most of these applications the measurement of pressure at the device tissue interface is required to either optimize the performance of the device (i.e. mammography) or to optimize the design of the device (i.e. wheelchair seating). See Figure 1 for a generalized measurement environment.

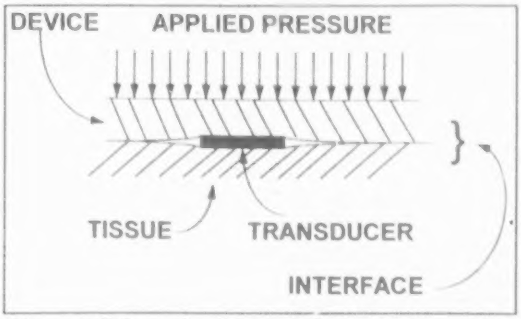


Figure 1: Schematic of the interface

A recent review of the literature demonstrates that a large variety of techniques for interface pressure measurements have been used making it difficult to compare the quantitative results from different types of transducers, even within one application area [1-8]. Currently, no standards exist that regulate the methods used in interface pressure measurements. A need, therefore, exists for the development of a general purpose interface pressure transducer that can be used in a variety of applications whose results can be reliably duplicated and compared.

OBJECTIVE

Ideal specifications for a tissue/device interface pressure transducer have been listed in the literature [9]. The authors have defined the following optimal specifications for an interface pressure transducer for biomedical applications:

i) output independent of tissue or device compliance;
ii)+/-2mmHg error, minimum hysteresis between measurements over 1 hr time period of +/-2mmHg;
iii) transducer design must permit its calibration by a clinical user in target applications;
iv) temperature compensated over target application temperature range;
v) resistant to moisture and other chemicals encountered in target applications;
vi) conforms to body curvatures in two dimensions having radii down to 2 cm;
vii) measures normal forces only (decoupling between normal and tangential forces);
viii) dynamic range covering target application pressure (0-500mmHg);
ix) 20 meas./sec sampling of static and dynamic pressures for the duration of the application;
x) pressure measurement of peak pressure averaged over a measurement area of no greater than 1 cm in diameter and less than 1 mm in thickness;
xi) radiotransparent for imaging applications;
xii)for applications requiring sterilization: gamma radiation, ethylene oxide or autoclave sterilizable;
xiii) complies with relevant IEC, ISO, and CSA standards;
ixv) fails in a mode that is obvious to the operator and safe for the patient;
xv) a reusable transducer should have a cost of manufacture of less than $50 each; if disposable

components are employed their replacement cost should be less than $1.

Once defined, a project was undertaken to develop an interface pressure transducer with the required specifications.

APPROACH

Transducers

A review of the literature provided an initial point from which to begin the research. A database of results and information pertaining to many of the transducers reported in the literature for interface pressure measurements was initiated. To supplement this database a variety of prototype and commercially available transducers were obtained for evaluation. A wide variety of technologies and have been categorized as follows:

i) force sensitive resistive material
ii) semi-conductor capacitor
iii) electro-pneumatic bag
iv) constant pneumatic flow valve
v) strain gauge on diaphragm
vi) strain gauge on diaphragm with back pressure

Calibration System

To test the transducers and evaluate the effect of interface compliance on pressure, a calibration system was designed and manufactured which simulated an interface environment based on a similar system described by Ferguson-Pell[8]. The system consists of a pressure chamber, sealing ring, membrane material, and a base plate (see Figure 2). For evaluation purposes each transducer was situated between the base plate and the membrane material and a pressure was applied through the membrane material. The system provided the ability to vary the interface material (and therefore the interface compliance) both above and below the transducer to assess the effects of a changing compliance on pressure measurement. The use of the calibration system allowed us to test the effect of one variable at a time while keeping all other variables constant.

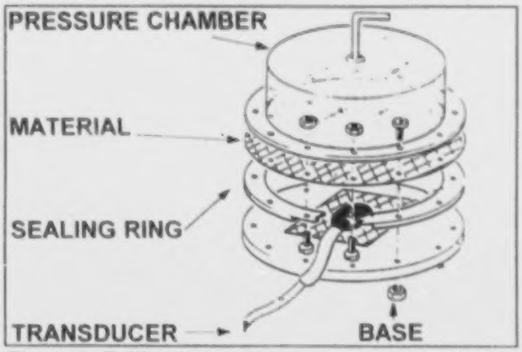


Figure 2: Calibration system

Testing

The objectives related to evaluation of currently existing transducers were two-fold: the first objective being to evaluate the transducers for their performance characteristics in an interface environment; and secondly, to compare the transducers with one another and rate them in the order of highest priority for continuing research. As such the testing procedure involved single measurements at various pressure intervals to obtain a calibration curve. Pressure was increased in intervals from 0 mmHg to a maximum of 450 mmHg, held for 15 minutes, and decreased in the same intervals back to 0 mmHg. In this way hysteresis and drift were also evaluated. As well, the transducers were tested between at least two materials of varying compliance to see what effect, if any, this would have on the transducer output.

RESULTS

The evaluation of the transducer types (i-vi) provided the following results:

i)the force sensitive resistive material transducers had over 20% hysteresis and drift;

ii) the four following transducers outputs were not independent of the material compliance against which they acted (see Figure 3 for an example of one transducer). Note that HCM stands for *high* compliance material and LCM stands for *low* compliance material in graphs and diagrams.

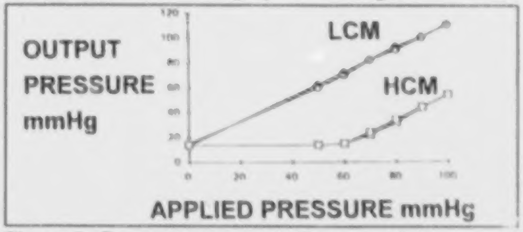


Figure 3: Constant pneumatic flow transducer

iii) the strain gauge diaphragm with back pressure output was found to be independent of the material compliance against which it acted (see Figure 4).

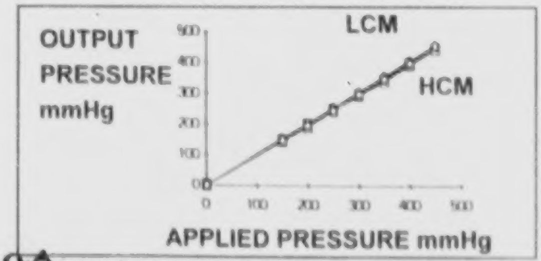


Figure 4: Strain gauged diaphragm, back pressure

BEST COPY AVAILABLE

DISCUSSION

A key characteristic of an interface pressure transducer that can be used in several applications is that it accurately measures the applied pressure independently of the material compliances. As demonstrated by the testing performed only the strain gauged diaphragm with back pressure type transducer behaved in this manner. This finding can be explained by analyzing the interaction between the pressure distribution and the compliance of the material applying the pressure. As the compliance of the material decreases, its ability to deform decreases, therefore the deflecting element of a transducer may respond differently to the same applied pressure depending on the compliance of the material applying the pressure (see Figure 5).

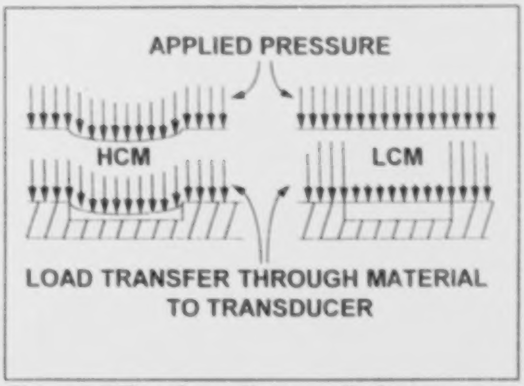


Figure 5: Effect of compliance on diaphragm

By eliminating the deflection of the diaphragm with back pressure we have effectively produced a transducer that responds to pressure independently of material compliance (see Figure 6).

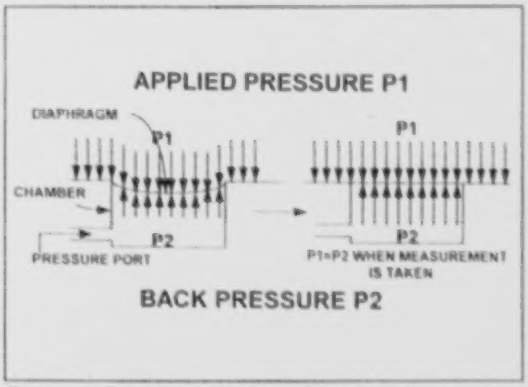


Figure 6: Compliance independent transducer

The authors are currently developing a second generation prototype of the strain gauge on diaphragm with back pressure transducer that will be temperature compensated and as thin as possible for use in clinical mammography trials.

Further research and development will work to overcome the curved surface condition that exists in many biomedical applications such as stump/sockets interfaces and tourniquet cuff/limb interfaces.

ACKNOWLEDGMENTS

The authors would like to thank the National Science and Engineering Research Council of Canada's Industrial Research Assistance Program for their funding of this project.

REFERENCES

1. J.A. McEwen, Biomedical Pressure Transducer. US Pat. No. 4,869,265, Issue date September 26, 1989.
2. J.A. McEwen,Tourniquet for Regulating Applied Pressures. US Pat. No. 5,048,536, Issue date September 17, 1991.
3. D.J. Clark et.al.,"Pressure measurements during automatic breast compression in mammography", J.Biomed Eng. 1990, Vol. 12, September.
4. J.M. Findlay, J.A. McEwen, et al.,"Automated Surgical Retraction Using an Advanced Robotic and a Pre-Robotic System",Proc CMBEC 17 (Banff,Al) pp.23-24, 1990.
5. J.C. Barbenel et.al,"Device for measuring soft tissue interface pressures",J. Biomed. Eng. 1990, Vol.12, November.
6. C.A. Harris, S.P. Pegg,"Measuring pressure under burns pressure garments using the Oxford Pressure Monitor", Burns (1989 15, (3),187-189.
7. M. Clark et.al,"Comparison of contact pressures measured at the sacrum of young and elderly subjects", J. Biomed. Eng. 1989, Vol. 11, May.
8. M. Lord et al.,"Foot pressure measurement: A review of clinical findings", J. Biomed. Eng. 1986, Vol. 8, October.
9. M.W.Ferguson-Pell,"Design criteria for the measurement of pressure at body/support interfaces", Eng. Med.1980,209-214.

Contact Address:
Nancy Paris-Seeley, P.Eng.
Dept. of Mechanical Engineering
University of British Columbia
2324 Main Mall
Vancouver, B.C.
V6T 1Z4
Tel: (604) 822-8785
FAX: (604) 822-2403
email: paris@mech.ubc.ca

BIOMECHANICAL EVALUATION OF SPASTICITY

J.R. Aitchison[+], D.P. Romilly[+], C. Hershler[+], R.E. Gosine[*]
[+]University of British Columbia, Department of Mechanical Engineering
Vancouver, British Columbia, Canada
[*]Memorial University of Newfoundland
St. John's, Newfoundland, Canada

ABSTRACT

The nature of spasticity is not fully understood and as a result, effective treatments for spasticity are required to alleviate this condition. Spasticity is currently measured clinically by subjective, manual methods which are unsuited to quantifying incremental day-to-day changes in severity required to evaluate new treatments. The current research project will use a recently developed computer controlled, motor driven device to quantitatively measure the degree of spasticity at the ankle. The device will be used to record the resistive torque at the subject's ankle and the associated muscle activity as well as the angular velocity and displacement arc of the test. Testing of normal subjects and subjects with spasticity should shed some insight into the nature of spasticity as well as provide a comparative evaluation of several established spasticity measurement protocols. Once a reliable method for the evaluation of spasticity is determined, the device will be used to evaluate new treatments for spasticity.

BACKGROUND

Spasticity is a condition which is often associated with head and spinal cord injuries, stroke, multiple sclerosis, and cerebral palsy. It can be defined as a velocity and position dependent resistance to passive stretching of the involved muscles. Motion of our limbs is accomplished when electric signals from the brain reach the agonist muscles via the motor neurons. Normally, the antagonist muscles are inhibited and provide no resistance to the movement, but a person with spasticity will have both agonist and antagonist muscles active. This results in increased muscle tone and resistance to stretch which causes a debilitating condition.

The nature of spasticity is not fully understood and as a result, treatment for this condition is limited to trial and error experimentation and conjecture. Currently spasticity is clinically measured manually by a therapist who manipulates the joint and qualitatively determines the degree of spasticity on an ordinal scale between low and severe (1). Unfortunately, this is highly subjective and thus is not accurate enough to adequately assess incremental changes in severity due to therapeutic intervention and treatment. In order to study the effectiveness of therapeutic intervention for spasticity, it is essential to have an objective, quantitative method of measuring spasticity.

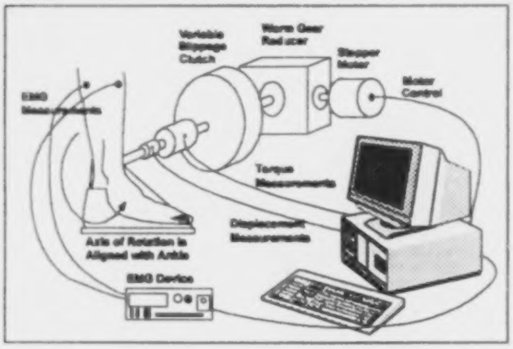
Although devices to measure spasticity do exist, none of them have been entirely successful in providing an acceptable measurement of spasticity. While, many of the various devices used to test for spasticity (2,3) rely on manual manipulations, there are several motor driven and computer controlled spasticity measurement systems available (4,5,6). Unfortunately, these measurement systems are all limited by design or application such that they either work only with voluntary forces applied by the subject, have limited velocity profiles for the manipulation of the joint, only evaluate passive mechanical stiffness, or are only used for either movement control (device moves subject) or torque control (subject moves device), but not both.

OBJECTIVE

The ultimate goal of this project is to provide the ability to suitably measure the results of therapeutic intervention and treatment, and, through a better understanding of the nature of spasticity, to develop superior treatments for this condition. The more immediate objectives of this research program are twofold. The initial objective is to develop a computer controlled device to quantitatively measure the degree of spasticity at the ankle in a clinically validated manner. This device should be flexible enough to accommodate testing via various experiment protocols (e.g. load controlled rotation, displacement/velocity controlled rotation, different knee-ankle positions, etc.). This device will then be used to obtain our subsequent goals, to determine the nature of spasticity by comparing the results of several measurement protocols and to use this data to determine a reliable method for the evaluation and measurement of spasticity and, if possible, to provide a therapeutic exercise program for people with spasticity.

APPROACH

A device to meet the objectives of this project has been developed (see Figure below).



Under a physician's supervision, the motor powered, computer controlled device will be used to measure the resistive torque to passive stretch about the ankle joint. Volunteers will insert their foot into a molded form mounted to a pedal type platform specially designed to hold the foot in place without exposing the subject's foot to any cold metal. The pedal is adjustable so that the axis of rotation of the ankle will line up with the axis of rotation of the device. With the subject attempting to relax the ankle joint, torque provided by a computer controlled stepper motor, increased via a worm gear reducer, and engaged through an electric clutch, will move the ankle through a predetermined rotation and velocity profile while both resistive torque and position measurements are simultaneously recorded. At the same time electromyography (EMG) measurements will be taken of the relevant muscles to determine the extent of electrical activity (i.e. activity of the muscle). The data output from the torque transducer, EMG transducers, and the potentiometer will be displayed to the user in near real-time on the computer screen. Tests will be repeated to assess the test-to-test and day-to-day reproducibility and to evaluate the effectiveness of therapeutic intervention. Test results will also be compared with the different measurement protocols developed by other researchers (4,5,6) to determine whether a systematic relationship exists between the various methods of spasticity evaluation. As safety is a major concern, the design incorporates a variable clutch which can be set to ensure the safety of the subject. If the amount of resistive torque exceeds a preset safe level, the clutch will slip preventing excessive torque. If a control or electrical failure should occur, a shear pin will break thereby ensuring the safety of the subject and providing a fail-safe system. The 'strength' of this mechanical fuse can be modulated by the use of different size shear pins.

The device will be evaluated statistically to assess its value as a clinical diagnostic tool. Initial testing on normals will be used to assess the suitability and repeatability of the device, as well as provide data as a control group for future comparison. In part, this data will be used to determine the amount of joint stiffness in normal ankle joints. Subjects with spasticity will then be tested to assess variations in spastic response due to parameters such as leg orientation (vertical/prone) and ankle position, ankle rotational velocity, applied weight etc. EMG measurement techniques will be utilized to detect muscle firing patterns for correlation with spastic response data. This information will be gathered on a variety of subjects exhibiting spasticity and will be correlated both day-to-day, person-to-person, and within disease groups. The goal is to better understand the effect of these factors on spastic response and to provide recommendations for treating spasticity in both a hospital and home environment.

DISCUSSION

Because the nature of spasticity is not fully understood, there is no general agreement on the most suitable way to measure spasticity. The intention of this project is to provide a concise and reliable method of evaluating and measuring spasticity at the ankle. If successful, the measurement technique would be applied to other parts of the body such as the elbow, knee etc.

The design and measurement protocol of the device will address the important factors which affect spasticity and spasticity measurement. For the subject these factors include:

- Varying torso and limb positions.
- Comfort and safety of the subject.
- Effect of body mass acting on muscle during activation (gravity effects).
- Active (subject moves the device) or passive (device moves the subject) measurement systems.
- Inherent joint stiffness of the subject.

For the control system the factors include:

- Load control versus displacement control.
- Velocity profile of the displacement.
- Ability to compare various measurement protocols.
- Comparing acquired data to preset safety standards.

Factors which affect the device design include:

- Effect of body mass acting on the muscle being tested.
- Comfort and safety of the subject.
- Active versus passive measurement.
- Portability of the device to allow it's use at a patients bedside.
- Adaptability of the device to a variety of positions including prone, lying, sitting etc., as well as to a variety of foot dimensions.
- Flexibility of the device to adapt to the various measurement protocols as well as measurement at other joints.

In addition, the device will allow measurement of spasticity while weighting the ankle to study the effects of gravity on spasticity (such as induced while standing and walking). This is an important factor in spasticity measurement that until now has not been studied in conjunction with the quantification of spasticity.

Because of the lack of understanding of spasticity, there is great potential and need for the development of a new treatment for this condition. In order to study the effectiveness of therapeutic intervention, it is essential to have an objective, quantitative method of measuring spasticity. The device developed by the current project will allow quantitative measurement of spasticity with enough accuracy to determine the day-to-day variations in spasticity, thus allowing suitable evaluation of new treatments.

The device may also have potential as an exercise device for people with spasticity. Movement of the joint is very important in the maintenance of that joint. Under certain circumstances, spasticity is not apparent in the muscles of people with spasticity. By moving the ankle joint, at various orientations of the leg and ankle, through various ranges of ankle movement and at various angular velocities while recording the muscle activity, the conditions where movement can occur without a spastic response can be determined. The device can record these conditions which could be subsequently programmed and executed by the device for use as an individualized stretching exercise regiment. This would provide the spastic individual with the capability of regulated stretching without spastic interference. There is a possibility that by moving the joint through various positions without experiencing spasticity, the subject may learn to move in a like manner without evoking a spastic response.

ACKNOWLEDGMENTS

Funding for this project is being provided by the Natural Sciences and Engineering Research Council of Canada.

REFERENCES

1. Katz, R.T., Rovai, G.P., Brait, C. and Rymer, W.Z. (1992). "Objective Quantification of Spastic Hypertonia: Correlation with Clinical Findings.", Archives of Physical Medicine and Rehabilitation, 73:339-347.

2. Chabal, C., Schwid, H.A. and Jacobson, L. (1991). "The Dynamic Flexometer: An Instrument for the Objective Evaluation of Spasticity.", Anesthesiology, 74:609-612.

3 Lin, J, Brown, J.K, and Brotherstone, R. (1994). "Assessment of Spasticity in Hemiplegic Cerebral Palsy. II: Distal Lower-limb Reflex Excitability and Function.", Developmental Medicine and Child Neurology, 36:290-303.

4. Sinkjaer, T. t al. (1993). "Non-reflex and Reflex Mediated Ankle Joint Stiffness in Multiple Sclerosis Patients with Spasticity.", Muscle & Nerve, 16(1):69-76.

5. Seib, T.P., Price, R., Reyes, M.R. and Lehmann, J.F. (1994). "The Stimulation.", Archives of Physical Medicine and Rehabilitation, 75:746-750.

6. Harburn, K.L., et al. (1992). "Spasticity Measurement in Stroke: A Pilot Study.", Canadian Journal of Public Health - Supplement 2, 83:S41-S45.

Contact Address:
Jeff Aitchison
Department of Mechanical Engineering
University of British Columbia
2324 Main Mall
Vancouver, British Columbia
Canada V6T 1Z4
Tel.: (604) 822-8785
FAX: (604) 822 2403
Email: aitchiso@mech.ubc.ca

THE EFFECT OF WRIST POSTURE ON THE GRIP STRENGTH OF PERSONS WITH CEREBRAL PALSY: IMPLICATIONS FOR TOOL AND TASK DESIGN

Janis G. Krohe
Rehabilitation Engineering Research Center
Cerebral Palsy Research Foundation of Kansas, Inc.
Wichita, KS

Tycho K. Fredericks
Department of Industrial and Manufacturing Engineering
Rehabilitation Engineering Research Center
Wichita State University; Wichita, KS

ABSTRACT

The objective of this study was to examine the effect of deviated wrist postures on the grip strength of male subjects with spastic cerebral palsy. The grip strength of 15 subjects was measured with the wrist in neutral posture, maximum flexion, and maximum extension. Results indicated that wrist posture has a significant effect on grip strength. Grip strength in maximum flexion was reduced by as much as 80% for some subjects with an average reduction of 44%. Comparisons were made with other studies of grip strength in persons with cerebral palsy and grip strength in deviated wrist postures for able-bodied populations. The results emphasize the importance of wrist posture in tool and task design.

BACKGROUND

Grip strength is an important parameter in the design of manual tasks. Knowledge of the grip strength of the worker is important so that tasks may be designed within the abilities of the worker. This is especially important when designing for persons with disabilities. If tasks are designed for an able-bodied population without knowledge of the abilities of a population of persons with disabilities, then tasks may be too difficult for them to perform. It is the objective of the rehabilitation engineer to enable persons with disabilities to accomplish desired tasks using engineering modifications and accommodations.

Many studies have been performed to obtain normative data on grip strength [1,2] and some have also determined the grip strength of persons with cerebral palsy [3]. Other studies have examined the effect of deviated wrist postures on grip strength [4,5]. This paper will present the results of a preliminary study investigating the effect of deviated wrist posture on the grip strength of male subjects with spastic cerebral palsy.

METHODS AND PROCEDURES

Subjects

Fifteen male subjects with spastic cerebral palsy participated in this study. All subjects were residents of The Timbers housing complex located in Wichita, Kansas.

Apparatus

The equipment used in this study consisted of a Jamar hydraulic hand dynamometer, an anthropometric measuring kit, and a goniometer.

Procedures

Standard anthropometric measurements were made of the subject's hand breadth (at metacarpals) and length (wrist crease to the distal end of the third finger) using the anthropometric measuring kit. The range of motion of the subject's wrist in the transverse plane was measured using the goniometer. The subject was seated with the shoulder 0° abducted and elbow flexed 90°. The subject flexed his wrist as far as possible in the transverse plane and the goniometer was used to measure the maximum flexion of the subject's wrist. This process was repeated until at least two measurements were obtained that were within 10% of one another. The above procedures were repeated with the subject's wrist in maximum extension.

Once the subject's wrist range of motion for his dominant hand had been determined, sampling of grip strength in the transverse plane in neutral, maximum flexion, and maximum extension wrist postures was performed. For each test of grip strength, the subject was seated with the shoulder 0° abducted, elbow flexed 90°, forearm mid-pronated, and wrist in either maximum flexion, maximum extension, or neutral wrist posture. The dynamometer was presented to the subject who was allowed ample time to achieve a good grasp on the handle and position his arm, forearm, and wrist in the prescribed manner. Using the Caldwell protocol, the subject was asked to gently squeeze the handle slowly up to maximum voluntary contraction and sustain that force for two seconds. At least one minute of rest was permitted between trials and no fewer than two trials were made to ensure values obtained were within 10% of one another. The procedure was repeated with the wrist in each of the remaining postures. The order of trials for the subjects was randomized.

RESULTS

Descriptive statistics for the 15 male subjects with spastic cerebral palsy are presented in Table 1.

Table 1 Subject Descriptive Statistics (n=15)

Measure	Mean	Std Dev.	Range
Age (years)	37.9	6.1	30 - 50
Stature (cm)	170.5	8.7	152.4 - 185.4
Weight (kg)	80.0	23.8	48.1 - 138.3
Hand Length (cm)	19.2	0.8	18.2 - 20.5
Hand Breadth (cm)	9.1	1.1	7.6 - 11.9
Flexion (°)	55.0	12.6	29.5 - 75.5
Extension (°)	53.1	20.5	21.0 - 79.5

The grip strength in the neutral posture was compared with studies by Roozbazar [3], Imrhan [6], Fernandez, et al. [7], and Mathiowetz, et al. [1] (Table 2). All comparison studies, except the Roozbazar study, utilized able-bodied subjects. A t-test revealed no significant difference between grip strength in the neutral posture in this study and Roozbazar's [3] study of 78 males with cerebral palsy. It can be assumed from this comparison that findings from the present study could be representative of a larger population of males with cerebral palsy.

Table 2 Grip Strength Studies [Mean(STD)]

Measure (kg)	Current (N=15)	Roozbazar (1978) (N=78)	Imrhan (1991) (N=30)	Fernandez, et al. (1991) (N=15)	Mathiowetz, et al (1985) (N=35)
Grip Strength	23.7 (14.5)	23.3 (10.7)	49.3 (7.7)	46.0 (6.7)	54.3 (10.9)

As expected, comparisons to able-bodied studies showed a significant difference in grip strength. Mean grip for the subjects with cerebral palsy is approximately 50% of the mean grip strength of able-bodied subjects. In addition, there is generally a greater variability in grip strength in the sample of persons with disabilities than in an able-bodied sample. It should be noted that in the current study, three of the subjects were within one standard deviation of the mean for able-bodied subjects.

An ANOVA was performed on a complete randomized block design with subjects used as blocks. The results of the ANOVA (Table 3) show that wrist posture has a significant effect on grip strength. Table 4 shows a summary of the mean and standard deviation for the grip strengths computed for the various postures.

Table 3 ANOVA Table for Grip Strength with Wrist Posture as Treatment

Source of Variance	SS	df	MS	F	p
Subjects	4046.41	14	289.03	7.34	$p<0.0001$
Posture	835.92	2	417.96	10.62	$p<0.0004$
Error	1102.43	28	39.37		
TOTAL	5984.76	44			

Table 4 Summary of Grip Strength (kg) for Various Wrist Combinations

Subject	Grip Strength (kg)		
	Neutral	Maximum Flexion	Maximum Extension
Mean	23.70	13.18	19.27
STD	14.47	5.83	11.15
Range	4.50 - 50.25	6.00 - 26.50	3.75 - 45.25

Duncan's multiple range test was performed on wrist posture. Results indicated that grip strength, with the wrist maximally flexed, had significantly lower values than either the neutral or maximum extended wrist postures. A decrease was seen when the wrist was in extension. However, the grip strength was not significantly different than the values obtained in the neutral posture.

Figure 1 presents a graphical illustration of mean grip strength in each wrist posture. Maximum grip strength was achieved with the wrist in a neutral posture for 11 of the 15 subjects. For these 11 subjects, there was a reduction in grip strength by as much as 80% with the wrist in maximum flexion. For the group (n=15), there was a 44% reduction in grip strength with the wrist in maximum flexion.. For the 11 subjects who obtained maximum grip strength in the neutral posture, a reduction range of 4% to 51% was seen with the wrist in maximum extension. For the entire group, the average reduction in grip strength with the wrist in maximum extension was 19%. The results compare favorably with Terrell and Purswell [4] who found that grip strength declined by 22% with the wrist in extension and 30% with the wrist in flexion. It should be noted that four

BEST COPY AVAILABLE

subjects did obtain maximum voluntary contraction (MVC) with the wrist in a posture other than neutral. One subject achieved MVC with the wrist in maximum flexion. The three remaining subjects obtained MVC with the wrist in maximum extension.

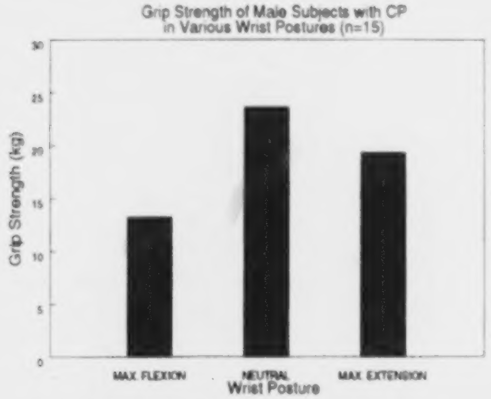


Figure 1 Mean Grip Strength vs. Wrist Posture

The decrease in grip strength as the posture of the wrist is deviated, coincides with Kraft and Detels' [5] study of able-bodied subjects. In their study, it was found that wrist flexion had a significant effect on grip strength, and that grip strength with the wrist extended did not differ significantly from the neutral posture. The same trend is seen in this study with a population of males with cerebral palsy. In both cases, designers should avoid awkward postures when structuring tasks.

CONCLUSIONS

Many activities require grip strength with the wrist in a posture other than neutral. As a result, it is important to consider deviated wrist postures when examining manual tasks requiring grip strength. This becomes even more serious when considering that many tasks and tools are designed for an able-bodied population who possess average grip strengths 50% greater than persons with disabilities. The results of this study should be considered in the design of handtools and the workplace in the employment of persons with cerebral palsy.

REFERENCES

1. Mathiowetz, V., Kashman, N., Volland, G., Weber, K., and Dowe, M. (1985). Grip and pinch strength data: Normative data for adults. Archives of Physical Medicine and Rehabilitation, 66, (6), 69-74.

2. Kellor, M., Frost, J., Silberberg, N., Iverson, I, and Cummings, R. (1971). Hand strength and dexterity: Norms for clinical use. American Journal of Occupational Therapy, 25, 77-83.

3. Roozbazar, A. (1978, Summer). Ergonomics in rehabilitation engineering. Problem Solving with Rehabilitation Engineering: Tech Brief, Wichita, Kansas: Cerebral Palsy Research Foundation, Rehabilitation Engineering Center.

4. Terrell, R., and Purswell, J. (1976). The influence of forearm and wrist orientation on static grip strength as a design criterion for handtools. Proceedings of the Human Factors Society 20th Annual Meeting. Santa Monica, CA: Human Factors Society.

5. Kraft, G.H., and Detels, P.E. (1972). Position and function of wrist. Archives of Physical Medicine and Rehabilitation, 53, (6), 272-275.

6. Imrhan, S.N. (1991). The influence of wrist position on different types of pinch strength. Applied Ergonomics, 22, (6), 379-384.

7. Fernandez, J.E., Dahalan, J.B., Halpern, C.A., and Viswanath, V. (1991). The effect of wrist posture on pinch strength. In Proceedings of the Human Factors 35th Annual Meeting (pp. 748-752). San Francisco, CA: Human Factors Society.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. Jeffrey Fernandez for his advice and support of this study and the subjects who gave freely of their time.

Janis Krohe
Cerebral Palsy Research Foundation of Kansas
2021 N. Old Manor
Wichita, Kansas 67208

VAN NES ANATOMICAL AND PROSTHETIC JOINT MOTION AND CO-FUNCTION; TOWARDS DESIGN MODIFICATION OF THE VAN NES PROSTHESIS

Melissa C. Carson[1,2], Stephen Naumann[1,2], William Cleghorn[2], Morris Milner[1,2]
[1]The Hugh MacMillan Rehabilitation Centre, Rehabilitation Engineering Department
[2]The University of Toronto, Toronto, Ontario

ABSTRACT: Van Nes (1950) described a surgical technique to manage congenital shortening of the femur through knee fusion and foot rotation by 180 degrees, called rotational osteotomy. The Van Nes prosthesis then allows for some foot control over the prosthetic knee joint motion. This study examined; 1) rotated ankle characteristic motions; 2) rotated ankle and prosthetic knee joint co-function for two subjects, with the goal to improve the Van Nes prosthesis design and, ultimately, functional ability.

Two distinct characteristic rotated ankle joint axes were found in both subjects; a hinge-like axis similar to the talocrural axis of normal subjects, and a skewed axis opposite to the normal subtalar axis orientation when projected onto the subject's frontal plane. The analysis of prosthetic joint and rotated ankle co-function showed similar results for both motion strategies. These co-function analysis results indicated that a dual axis prosthetic knee joint could be advantageous in facilitating improved performance in walking and play activities, possibly resulting in better gait efficiency and higher maximum knee flexion angles.

BACKGROUND: The Van Nes prosthesis is shown in Figure 1a, with subject anatomy pre-surgery and post-surgery in Figure 1b. A few studies evaluated Van Nes prosthetic fit and alignment with respect to comfort and function[1,2,3,4,5]. However, little has been investigated on the actual design of the knee component (a hinge joint), and skew motion of the rotated foot, out of the sagittal plane (the plane of forward progression), creates difficulties in fitting the prosthetic hinge relative to the rotated ankle using standard clinical techniques.

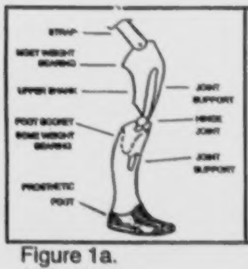


Figure 1a. A Van Nes Prosthesis.

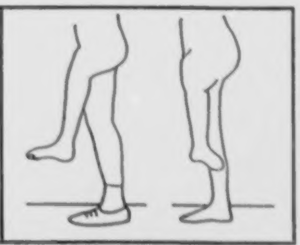


Figure 1b. Congenital short femur (left), post-rotational osteotomy (right).

Comparisons between the prosthetic knee range of motion (ROM) versus rotated ankle joint ROM show reported discrepancies of as much as 40°, and these results vary widely[5,6,7,8]. The prosthetic knee, in general, achieves less ROM. Although clinical reasons exist for differences in individual cases, such a wide range of results indicated a lack of guidelines to maximize ROM for optimal function.

Functional performance levels of Van Nes subjects are reportedly slightly higher than that of above-knee (AK) amputees in terms of energy cost[9,10], and gait characteristics[8,9,10]. Below-knee (BK) amputees are functionally superior to both Van Nes and AK groups. Overall a wide range of functional results for Van Nes subjects was reported. As AK type amputation is an alternative to rotational osteotomy, it is desirable to improve overall Van Nes functional results. High performance levels achieved previously, in addition to input from clinicians, indicated a potential for improving functional levels of Van Nes subjects, particularly through examination and modification of the prosthetic hinge joint design, due to lack of previous research in this area.

RESEARCH QUESTIONS: The broad question was; can Van Nes function be improved through modification of the prosthetic joint design? How? Background review indicated a need for more fundamental knowledge. Two specific questions, then, were addressed by this research:

(1) What are the biomechanical characteristics of the rotated ankle joint for individual subjects?
(2) How does the design of the prosthetic joint affect its co-function with the anatomical joint?

METHOD: An experimental analysis, performed to determine rotated ankle characteristic motions during gait, had two main design goals; to be prosthesis independent and to simulate gait. As Van Nes subjects cannot use upright bi-pedal gait without the prosthesis, the apparatus, Figure 2, was designed to induce active contractions of the ankle flexor and extensor muscles through the joint ROM, as would occur about the (affected) knee in Van Nes, BK or normal gait. Moment loads were centred about the malleolus, similar to the prosthetic joint position, through linkage to an off-set wheel.

BEST COPY AVAILABLE

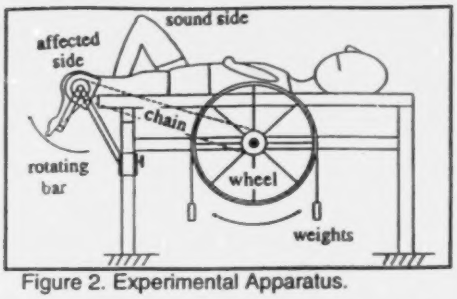


Figure 2. Experimental Apparatus.

A camera based system, VICON, selected for its accuracy (assumed isotropic error ±0.5 cm[13]) yet non-invasive technique, was used to determine the three-dimensional positions of six reflective markers, adhered to anatomical landmarks on the forefoot[12] and shank[13]. Instructions were to flex and extend to the limits of the ROM with a controlled movement. Exact wording was selected in practice trials for each subject.

Evaluation of the spatial marker position-time data[13] used a kinematic technique, screw axis theory, to identify the instantaneous ankle axes of rotation through the ROM. Screw axis theory methods, applied in several biomechanical studies[14,15,16,17,18,19], were optimized using an objectively applied reliability criteria, to identify results reflecting the true motion of the joint.

Analysis of prosthetic hinge and rotated ankle joint co-motion was performed to determine how the fit or positioning the prosthetic hinge joint, and hence joint design, could influence Van Nes function. The prosthetic hinge ROM and moment were compared to those of the rotated ankle, using the experimental data, for 100 theoretical positions of the hinge joint, given by the grid intersection points on a 10 cm by 10 cm grid centred over the malleolus, Figure 3.

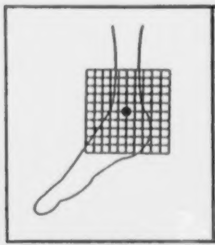


Figure 3. Hinge joint position grid, 10x10 cm, centred at the malleolus in the sagittal view.

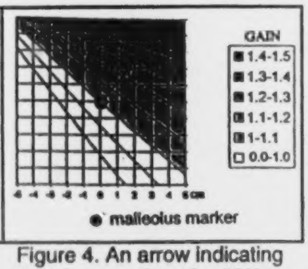


Figure 4. An arrow indicating the hinge position for 20% to 30% ROM gain, for ankle flexion between 40° and 50°.

Consecutive small motions of the rotated foot were examined through the ROM. Results were expressed as ratios of; prosthesis angle change over rotated ankle angle change, and moment about the prosthetic joint over moment exerted about the rotated ankle, for each prosthetic hinge position.

A sample result, Figure 4, shows the ROM ratios or gains in contour format for the grid analogous to Figure 3. The average of all grid positions achieving gains of 20% to 30% was selected to represent each result, which were then superimposed, to summarize the hinge position characteristics.

RESULTS: Two characteristic rotated ankle motions or strategies, identified from their instantaneous axes of rotation, were found to be similar for both subjects; hinge-like motion, and twisting motion. Subject 1 used both motions under all loading conditions. Subject 2 used twisting motion during concentric muscle contractions and hinge-like motion during eccentric contractions.

The axis of rotation for a typical hinge-like motion result corresponded to one of the two normal ankle axes, the talocrural axis[20]. The twisting motion strategy was indicated by an average skew axis of that ran close to the spatial centre of the joint, and tilted distal and posterior on the lateral side in both subjects affected on the right side. The skew axis of the normal ankle joint, the subtalar axis, would have had an opposite orientation in normal subjects projected onto the frontal plane.

The hinge joint position characteristics, given by a summary of the gain ratios for both moment and ROM analysis, were similar for both subjects and both motion strategies, most likely because both axes pierced close to the spatial centre of the joint. A typical result, Figure 5, shows the hinge joint position characteristics on the 10x10 cm grid corresponding to Figure 3.

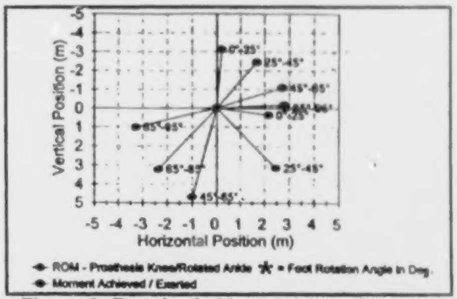


Figure 5. Prosthetic hinge joint position characteristics (grid from Figure 3).

The opposing prosthetic hinge position shift directions from the malleolus, for ROM and moment gains, indicated that the optimal position would be close to the malleolus, as it is currently fit in clinics. However, two critical components of function, walking and play activities, were then examined independently, to further utilize these results.

Facilitating a bent knee during the stance phase of gait was considered one key to developing potential functional improvements for Van Nes subjects since, an extended locked knee stance requires raising the body centre of gravity during each gait cycle and is thus less efficient. Bent knee stance could be aided by increasing the moment about the prosthetic knee over that exerted at low joint flexion angles, through a hinge joint shift proximal and anterior to the malleolus (up and right on the grid shown), Figure 8. The slight loss of ROM would be insignificant since only low flexion angles are used during stance, upto approximately 20° in normals[21].

Increasing the maximum knee flexion angle was considered another key to facilitating function, used in the swing phase of gait and running, and in play activities such as kneeling and bicycling, when knee joint moments are generally zero. A gain in ROM could be achieved by moving the hinge joint distally and posterior to the malleolus, (down and left on the grid shown), Figure 8.

Existing dual axis joints allow for the use of two distinct joint centres dependent on the joint flexion angle, as would be required to implement both strategies mentioned here. Thus, these two tactics or a combination of a centred and an off-set prosthetic joint axes could be practically implemented into a prototype and ultimately a clinically useful parametric design.

DISCUSSION: The presence of the same two rotated foot motion strategies in two subjects has shed the first light on a detailed understanding of the Van Nes rotated ankle joint motion. The presence of a characteristic hinge-like motion was considered advantageous, since a greater range of motion was observed in both subjects when using this strategy but also because this indicates a potential for facilitating hinge joint fit This preliminary insight into Van Nes ankle joint function has also indicated that the relationship between it and the prosthetic joint function relies more on joint fit than on ankle joint characteristics, when the contact point or area between the socket and foot can be reliably estimated.

The analysis of the hinge joint position characteristics has laid the ground work for design and evaluation of a modified prosthetic knee joint. Hinge positions advantageous for facilitating both bent knee stance and an increased maximum prosthetic knee flexion angle were analysed, and this information could be tailored to the needs and abilities (strength and existing ROM) of individuals. The impact of improved function, should it be achieved in practice, could affect; daily activities, choices and energy levels of Van Nes subjects. Positive functional application of these findings could also influence decisions of congenital short femur patients as to their selection between surgical alternatives, as well as influencing techniques of prosthetic fit and post-surgery gait training.

REFERENCES:

[1] Weick et al., J of ACPOC, 26:1:28, 1991.
[2] Hall and Bochmann, in Proximal Femoral Focal Deficiency, p.77-99. 1969.
[3] Osborne et al., J of ACPOC, 27:2:60. 1991.
[4] Krajbich, Hubbard, J of ACPOC, 26:1:28. 1991.
[5] Knahr et al., Ortho., 10:9:T241. 1987.
[6] Murray et al., J B & J Surg., 67A:3:392. 1985.
[7] Friscia et al., J B & J Surg., 71A:9:1386. 1989.
[8] Glynn, Internal HMRC Report, 1982.
[9] Cammisa et al., J B & J Surg., 72A:10:1541. 1990.
[10] McClenaghan et al., J B & J Surg., 1989.
[11] Keuppfer, Work Term Report, HMRC, 1993.
[12] Kidder et al.,East Coast Clin Gait Lab Con, 1992.
[13] Apkarian et al., J Biomech., 22:2:143. 1989.
[14] Kinzel et al., J Biomech., 5:93. 1972
[15] Panjabi et al., J Biomech., 14:447. 1981.
[16] Blankevoort et al., Biomech., 23:12:1219. 1990.
[17] Winters et al., Spine, 18:9:1178. 1993.
[18] An et al., Biomed Sci Inst., 27:245. 1991.
[19] DeLange et al., J Biomed Eng., 112:107. 1990.
[20] Inman, Human Walking, Williams/Wilkens, 1981
[21] Colborne et al., Am J Phys Med Rehab, 71:272. 1992

ACKNOWLEDGEMENTS: Many thanks to the following institutions for their financial support:
- The Natural Sciences and Engineering Research Council of Canada,
- The Easter Seals Research Institute,
- The Hugh MacMillan Rehabilitation Centre,
- The University of Toronto.

Authours' contact addresses:

Melissa C. Carson.
1 square Jasmin,
75016 Paris,
France

Stephen Naumann
HMRC, 350 Rumsey Road
Toronto, Ontario
M5G 1R8, Canada.

BEST COPY AVAILABLE

A METHOD FOR COMPARISON OF CONTIGUOUS GROUND REACTION FORCE DATA AND SINGLE STANCE GROUND REACTION FORCE DATA

Ken J. Stewart, Rory A. Cooper, Rick N. Robertson
Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Sciences
University of Pittsburgh, Pittsburgh, PA 15261

As meaningful dual stance phase data becomes a viable form of ground reaction force data, we need a method for comparing this data to the more traditional form of single stance ground reaction force data. This paper presents a method for manipulating single stance ground reaction force data for the prediction of dual stance ground reaction force data. Data from a standard floor mounted force platform and an instrumented treadmill that measures contiguous gait cycles were collected. The single stance data from the force plate were manipulated according to the method presented in this paper. The correlation coefficients for the Fx, Fy, and Mz components from the force plate and treadmill data sets are calculated to be 0.8790, 0.8790, and -0.9252, respectively. Dual stance data has the potential to provide a much higher understanding of the mechanisms of gait as approximately 1/3 of the ambulation process is spent in the dual stance phase.

INTRODUCTION

With the development of new instrumentation which measures the ground reaction forces of contiguous gait cycles, it becomes necessary to develop a method for the quantitative comparison of this dual stance reaction force data to that of the standard single stance force data. Davis and Cavanagh[1] have developed a methodology for the decomposition of superimposed vertical ground reaction forces into left and right force profiles. However, the instrumentation used by Davis and Cavanagh to collect the reaction force data in this study did not measure the horizontal reaction forces. There have been attempts by others[2] to rationalize the neglect of the horizontal components in contiguous gait reaction force measurements. These forces are necessary for the subsequent calculation of net joint reaction forces and moments. The data presented in this paper were collected on an instrumented treadmill that measures the ground reaction forces of contiguous gait cycles in the sagittal plane. In order to establish the efficacy of the measurements of the treadmill, a method for quantitative comparison of this dual stance reaction force data to that of the more widely published and familiar single stance force data was developed.

METHODS

Single stance data from a standard floor mounted force platform (AMTI Model OR6-5) were collected for a 28 years old subject weighing 934 N. The coordinate axes for both measurement devices are defined as positive x in the direction of ambulation, positive y is up, and positive z to the subjects right. The two dimensional force and moment profiles of one stance phase of this data are isolated and superimposed over itself by 25% (Figures 1, 3, and 5). The percent overlap is determined by the following equation.

$$\left(\frac{\text{dual stance phase (sec)}}{\text{complete stance phase (sec)}}\right) 100\%$$

The overlapping waveforms are then summed and the results are presented in Figures 2, 4, and 6.

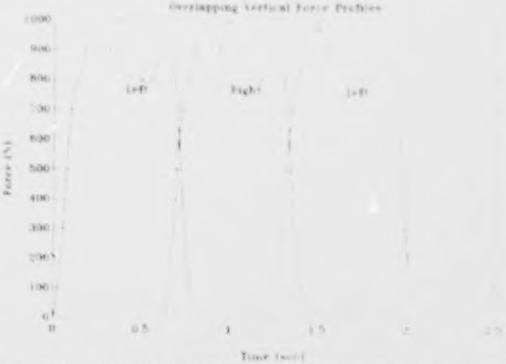


Figure 1. Vertical force profiles for three contiguous steps

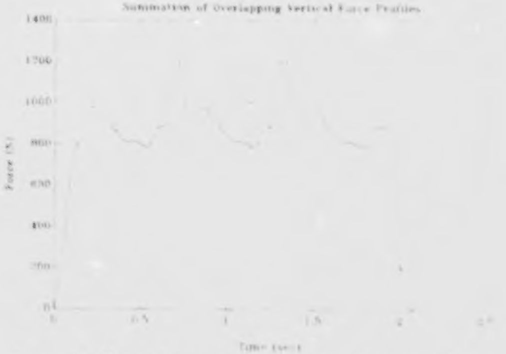


Figure 2. Sum of superimposed vertical force profiles

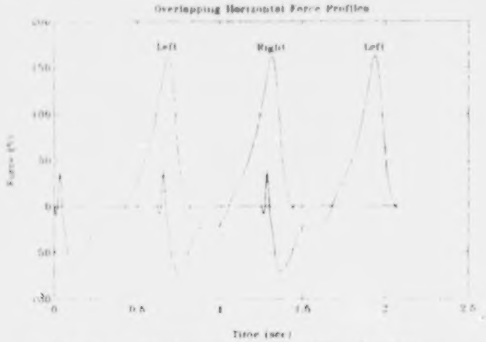


Figure 3. Horizontal force profiles for three contiguous steps.

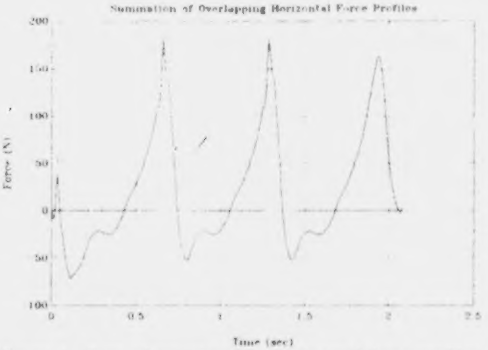


Figure 4. Sum of superimposed horizontal force profiles.

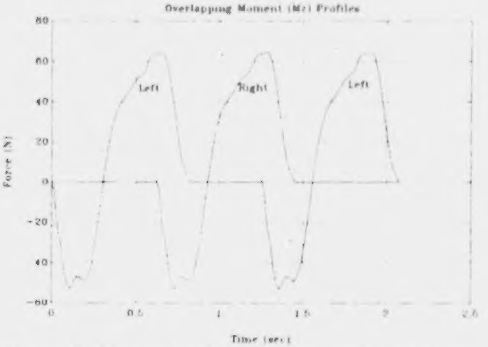


Figure 5. Moment profiles for three contiguous steps.

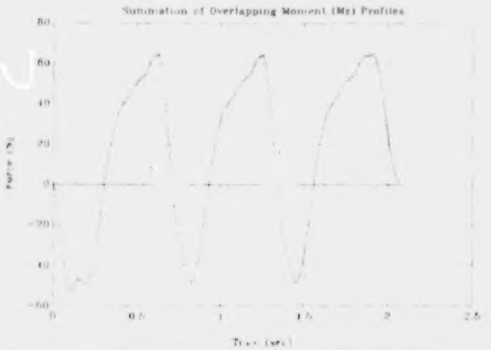


Figure 6. Sum of superimposed moment profiles.

The resulting waveforms of the summed superimposed profiles are then parsed to isolate the complete stance phase of one step.

Data from the force sensing treadmill were also collected using the same subject. One complete stance phase of one step of the treadmill data was isolated. At this point, there is a representative waveform from both the force plate and treadmill that include dual stance phase periods. Since the corresponding arrays of data must contain the same number of data points to calculate the correlation coefficient, it was necessary to spline the shorter of the two data sets. To accomplish this a Matlab[3] function was written which utilizes a cubic spline data interpolation function within Matlab to lengthen the shorter of the two data arrays. The *corrcoef* function within Matlab was then implemented to calculate the correlation coefficient of the force plate and treadmill waveforms.

RESULTS

The correlation coefficients for the Fx, Fy, and Mz components from the force plate and treadmill data sets were calculated to be 0.8790, 0.8790, and -0.9252, respectively. It must be noted that the correlation coefficient for the Mz component is negative due to the sliding of the foot relative to the coordinate system of the treadmill. On the force plate the center of pressure (CoP) migrates in the positive x direction due to foot role while during treadmill walking the CoP migrates in the negative x direction as a result of the rotating belt. The waveforms used to calculate these correlation coefficients are presented in Figures 7,8, and 9.

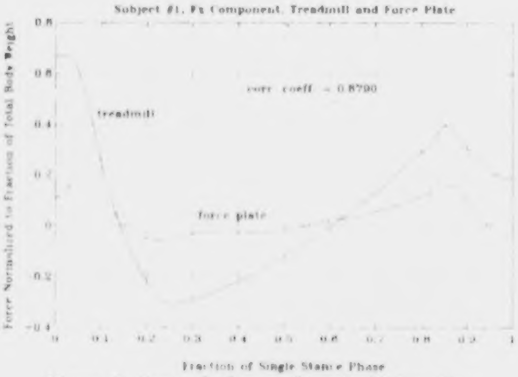


Figure 7. Force platform and treadmill data (Fy) for one complete stance phase.

BEST COPY AVAILABLE

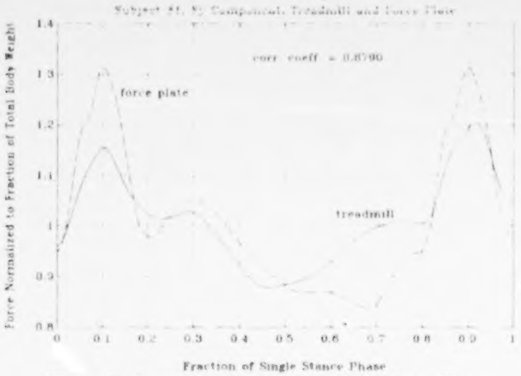


Figure 8. Force platform and treadmill data (Fx) for one complete stance phase.

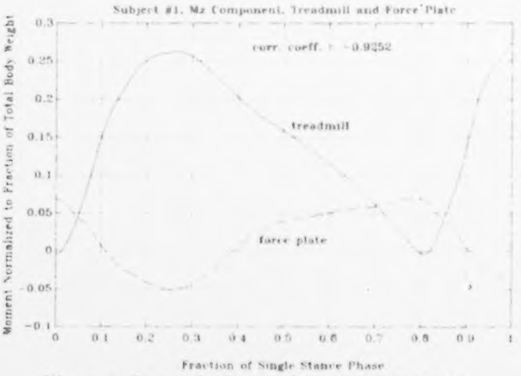


Figure 9. Force platform and treadmill data (Mz) for one complete stance phase.

CONCLUSIONS

As the use of clinical devices that measure the ground reaction forces for contiguous gait cycles in two and three dimensions becomes more common and widespread, this method for comparing dual stance phase data may become less important. But as this type of dual stance phase data is in the early stages of analysis and understanding, a method such as this is of great value in determining the efficacy and accuracy of such devices.

Dual stance data has the potential to provide a much higher understanding of the mechanisms of gait as approximately 1/3 of the ambulation process is spent in the dual stance phase. Standard ground mounted force platforms do not provide the means for biomechanists to analyze and study this portion of ambulation. As more dual stance phase data is collected and analyzed, we will develop a more accurate understanding of ambulation mechanisms.

ACKNOWLEDGMENTS

This research was partially supported by the US Department of Education Rehabilitation Services Administration.

REFERENCES

[1] Davis, B.L., P.R. Cavanagh. Decomposition of superimposed ground reaction forces into left and right force profiles. *Journal of Biomechanics*, 26(4/5): 593-597, 1993

[2] Stewart KJ, Cooper RA, and Robertson RN. The Analytical Inadequacies of Treadmill-Mounted Force Platforms. *Proceedings 17th Annual RESNA Conference*, Nashville, TN, 1994.

[3] The Student Edition of Matlab, Prentice-Hall, 1992.

Ken Stewart
11824 133rd St. Ct. E
Puyallup, WA 98374

PILOT STUDY ON ANKLE-FOOT ORTHOSIS LOADING DURING GAIT TO DETERMINE THE STRESS DISTRIBUTION FOR FINITE ELEMENT MODELLING

Kimberley E. Parker[1,2], Stephen Naumann[1,3], William L. Cleghorn[2]
The Institute of Biomedical Engineering[1] and Mechanical Engineering Department[2], University of Toronto,
and The Hugh MacMillan Rehabilitation Centre[3], Toronto, Ontario, Canada

Abstract

Through finite element analysis, new materials and design modifications of orthotic devices can be investigated in order to decrease their cost and time of fabrication. To accurately model these complex systems a knowledge of the loads that an orthosis undergoes during functional activities is required.

A method of obtaining interface pressures between an ankle-foot orthosis (AFO) and a subject is presented and evaluated. A preliminary trial was performed with a male adult subject utilizing thin sensors based on sensitive resistor technology. Sensors were placed under the toe, heel, 1st, 2nd and 5th metatarsal heads, medial and lateral ankle malleoli and cuff of the AFO. Peak plantar pressures were found in the range of 400 kPa to 2945 kPa for walking and jogging. These data suggest that the sensors are suitable for investigating the orthosis loading pattern during gait but care must be taken in the location and consequently landmarking of bony prominences and areas believed to be under high stress.

Background

Approximately 100,000 ankle-foot orthoses (AFOs) are prescribed for children and adolescents with neuromuscular disorders such as spina bifida and cerebral palsy in North America annually in order to limit unwanted movement and maximize functional activities. The current AFO fabrication process is a lengthy and labour intensive process, and requires at least two client visits. There is a need for the development of an AFO that can be prescribed in a single visit at a lower cost (1).

Methods of obtaining the loading conditions in previous finite element analysis studies of orthoses involved the use of tabulated data and schematics of the leg and orthosis assembly (2) or the modelling of the ankle-foot complex and the simulation of loads due to body weight (3,4). It was felt that a more direct approach of measurement of the stress distribution between orthosis and limb would result in a more accurate model.

There are various methods of determining the interface pressures between subject and orthosis. The use of piezoelectric transducers are limited due to their size and expense. Recently there has been extensive research directed towards the study of pressure distribution on the plantar surface of the foot using pressure sensing insoles (5,6,7,8). Such measurements are becoming an important clinical tool with patients with sensory neuropathy (5). The inexpensive cost of force-sensitive resistive pressure sensors (FSRs) have led to the popularity of their use in portable in-shoe plantar pressure data acquisition systems (6,7).

Objective

The objective of the research is to determine the interface pressures between the subject's limb and AFO during gait in order to obtain the stress distribution for use with finite element modelling. Areas of interest include the plantar surface and ankle malleoli regions of the AFO which are believed to contribute to the majority of the loading of the AFO. Development and evaluation of an interface pressure measurement system is initially required.

The ultimate goal of this research is to determine the required thickness of the AFO and effects of alteration of the orthosis trimlines with proposed new material combinations using the finite element method. Interface pressures measured during gait analysis will be applied to a digitized computer model of the AFO and a dynamic analysis will be performed. The research will be conducted through a case study with focus on a pediatric population. This research will further our understanding of the mechanical characteristics of the AFO and should also provide some idea on interface pressures that may be useful clinically.

Methodology

Pressure Sensors and Data Acquisition

Uniforce sensors (Force Imaging Technologies, Chicago, Il) were chosen based on their thin sensor design, durability, overloading capability, force sensing ranges available, and their relative low cost (5 sensors for $75.00). Their construction is based on force sensitive resistive technology consisting of pressure sensitive material mounted between two layers of substrate covered with a conductive material. As the sensor is loaded there is a decrease in resistance from 5 Meg-ohms to 20 k-ohms. The data acquisition system provides a 1 V potential to the sensor to avoid overheating. Two inverting operational amplifiers amplify the output voltage to a range of 0-5 V. Cables run from the sensors mounted on the AFO along a ceiling track to allow for movement across the length of the gait laboratory to the signal conditioning box where amplification of the signal takes place. A DT2801(Data Translation) signal-acquisition system installed on an IBM PC provides 16 channels of data acquisition with 12 bit resolution. The program Viewdac (Asyst Software Technologies, Inc.) was used to sample the sensors.

Calibration

Calibration of the sensors was performed using a lever system with a 1100 N strain gage load cell as a reference. The load was applied to the entire sensing area for each calibration trial. Sensors of range 0 to 7 MPa were calibrated before and after the preliminary trial. Calibrations after the trial were done for the range of loading experienced (0-3000 kPa) and these data were used.

The sensors are reported to experience hysteresis and are non-linear in response. Calibration provided a look-up table to compensate for the non-linearity of the sensor. Uniforce sensors are sensitive to temperature changes which will affect the output of the sensor. Levels of this sensitivity as of yet have not been determined but researchers have found the sensitivity of similar force-sensitive based technology to be -0.5% per degree Celsius full scale (6).

Trial Procedure

A preliminary trial was performed with a 79 kg male with normal gait parameters wearing an AFO on his right foot. The sensors were placed under the heel, large toe, 1st, 2nd, and 5th metatarsal heads through landmarking of these bony regions where peak pressures have been reported (7). As well, sensors were placed in both the medial and lateral ankle malleoli regions and two on the upper cuff of the AFO (figure 1). Sensors were taped in place with the sensing area facing the surface of the AFO.

Fixed to the sensing area of each sensor was a thin 6.4 mm diameter plastic disk to ensure that the entire sensing area was loaded in a consistent manner. A thin12.7 mm diameter plastic disk was placed on top of the sensor in order to cover a larger surface area. The subject was asked to walk, jog and jump with data sampled at 100 Hz for 15 seconds.

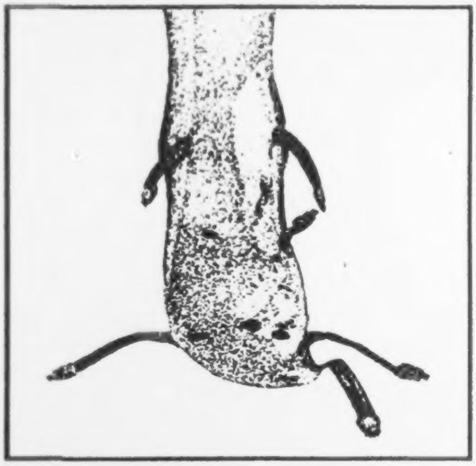


Figure 1, Sensor mounting on AFO.

Results

Calibration of the sensors indicates that the sensitivity of the sensor to be approximately 0.4 mV/kPa with a repeatability within 5% full scale. Sensors experienced hysteresis in the range of 15-20% full scale. The cadence of the subject in steps per second was 0.7 for walking and 1.2 for jogging. Figure 2 shows the range of pressures measured over 4 cycles of walking.

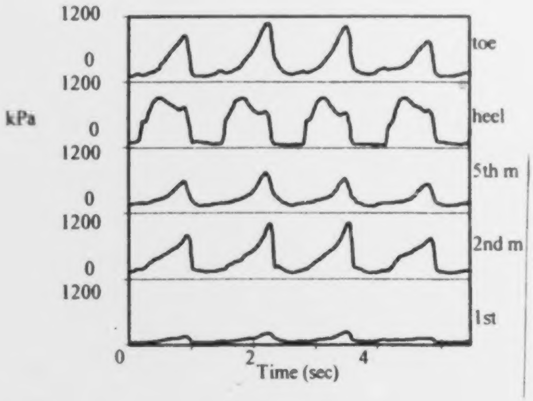


Figure 2, Interface pressures over time individually graphed between 0 and 1200 kPa baselines.

Table 1 shows the peak pressures recorded for the subject during a walking and jogging trial.

Location	Walk (kPa)	Jog (kPa)
toe	1289	2945
1st met.	162	154
2nd met.	1145	1145
5th met.	888	888
heel	1372	1984
medial ankle	455	441
lateral ankle	34	117

Table 1, Peak pressures recorded.

DISCUSSION

Results obtained for pressures under the first metatarsal head appear low indicating that the sensor was not accurately placed under the bony prominence. This indicates the need for a more accurate method of landmarking than visual. Future studies will involve the use of pressure print paper to determine the exact locations of the plantar surface bony prominence prior to sensor placement. The placement of sensors on other areas of the AFO will still require visual judgment.

The data obtained, although dependent on factors such as body weight, are close to previously reported results for peak pressures during walking in the ranges of 0-800 kPa (7). The higher range of peak pressures measured may be due to an increase of local pressure caused by the 12.7 mm diameter plastic disk placed between the sensor and limb. This method appears to be viable for obtaining the stress distribution during gait for a case study finite element analysis of an AFO.

Future work will involve a case study with a child with spina bifida. Interface pressures during gait and other functional activities will be obtained and used as boundary conditions for the computer model. It is proposed to collect strain gauge data simultaneously with pressure data for future validation of the computer polypropylene model.

ACKNOWLEDGMENTS

Funding provided by Natural Sciences and Engineering Research Council, Ontario Rehabilitation Technology Consortium (Ontario Ministry of Health) and The Hospital for Sick Children Foundation.

REFERENCES

1. Naumann, S., Lee, M., Wedge, J., Rang, M., Belbin, G. Development of a modular design, custom-fitted ankle-foot orthosis system. Internal Report, HMRC, 1992.
2. Granata, C., De Lollis, A., Campo, G., Piancastelli, L., Merlini, L. Analysis, design and development of a carbon fibre reinforced plastic knee-ankle-foot orthosis prototype for myopathic patients. J Eng Med, 1990, 204(2), 91-96.
3. Lam, P.C., Dowing, M., Reddy, N.P. One more step in redesigning the ankle-foot orthotic. Soma: Eng for the Hum Body, 1987,2(1),36-39.
4. Chu, T., Reddy, N.P., Padovan, J. Stress distribution in the ankle-foot orthosis during pathological gait due to "drop-foot". Proceedings RESNA '93, 1993, 192-194.
5. Lord, M., Hosein, R. Pressure redistribution by molded inserts in diabetic footwear: a pilot study. J of Rehab Res and Dev, 1994, 31(3), 214-221.
6. Wertsch, J., Webster, J., Willis, J. A portable insole plantar pressure measurement system. J of Rehab Res and Dev, 1992, 29(1), 13-18.
7. Zhu, H., Maalej, N. Webster, J., Tompkins, W., Bach-y-rita, P., Wertsch, J. An umbilical data-acquisition system for measuring pressures between the foot and shoe. IEEE Trans on Biomed Eng, 1990,37(9), 908-911.

Kimberley E. Parker
Rehabilitation Engineering Department
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, Ontario, Canada M4G 1R8
(416) 425-6220 x515
e-mail: parker@drill.me.utoronto.ca

ASSESSMENT OF EFFICACY OF SILICONE GEL-FILLED SHOE INSOLES FOR PLANTAR PRESSURE RELIEF

Quesada, P.M. and Sawyer, F.D.
Biomedical Enginineering Center & Division of Orthopaedics, Ohio State Univ., Columbus, OH 43210

ABSTRACT

In the investigation, presented here, we evaluated the efficacy of silicone gel filled insoles, for relieving elevated plantar pressures, in a manner consistent with the mechanism by which these gel insoles can provide such relief. Our study involved the computation of discrete gradients of pressure at the heel and forefoot, in addition to determination of peak plantar pressures at the heel and metatarsal regions. High pressure gradients are thought to be precursors to customary indications of ineffective orthotic insoles, such as high peak pressures.

BACKGROUND

Orthotic shoe insoles, which reduce elevated local pressures at the plantar foot/shoe interface, can be of substantial preventative and/or therapeutic value to a variety of patients. Plantar pressure reduction for patients with diabetes and sensory neuropathy would be extremely useful since elevated plantar pressure has been associated strongly with plantar ulceration in such patients (2, 3, 11, 14). Individuals with peripheral neuropathy associated with other pathologies (4, 5) also may experience benefits from plantar pressure reduction. Successful reduction of plantar pressure by means of orthotic shoe insoles dictates that insole materials have properties that are useful for redistributing load away from sites of localized elevated plantar pressure.

Several investigators have reported on the potential use of various materials and designs for use in orthotic pressure management (4, 6-10, 12, 13). Investigators generally have used parameters such peak pressures and pressure-time-integrals, at plantar surface regions of interest, to assess efficacy of such insole materials and designs. Such evaluative measures generally have been appropriate with regard to the mechanisms by which most orthotic insoles relieve elevated plantar pressure. Many insoles are formed from a single, high compliance, material (e.g., spenco, PPT) which can increase the area over which loads are applied, by virtue of their substantial deformation (primarily elastic) (1). Other insole designs (e.g., custom formed rigid insoles) seek to relieve plantar pressure in a given region by preferentially loading adjacent regions (1).

The mechanism by which the gel-filled insoles (Fig. 1), that were used in this study, can relieve plantar pressure differs substantially from the mechanisms of other insole materials and designs. These gel insoles can maintain nearly uniform pressure within the fluid and transmit such pressure across the upper surface. Thus, if without such an insole, elevated pressures exist adjacent to regions of low pressure, then a gel insole can reduce elevated pressures by distributing load equally across the contacting plantar surface. Plantar pressure reduction via use of gel-filled insoles, however, would seem to be most effective while fluid is present beneath the entire contacting plantar surface. When no fluid exists beneath a portion of the contacting plantar surface (Fig. 2), then that portion of the plantar surface is essentially in direct contact with the shoe sole, and substantial disparities in plantar pressure can persist.

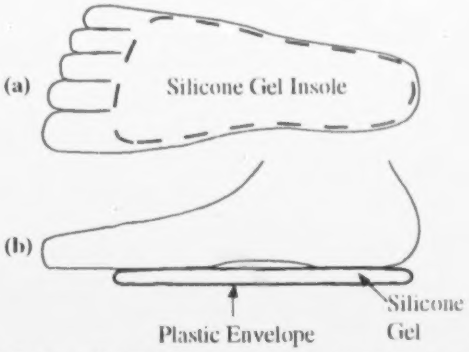


Fig. 1 Sketch of foot with silicone gel insole: (a) dorsal view, (b) medial view

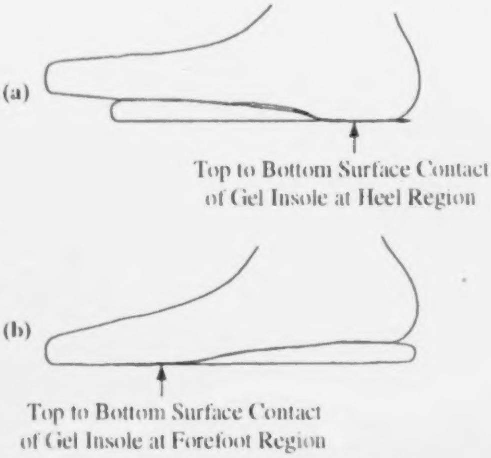

(a)
Top to Bottom Surface Contact of Gel Insole at Heel Region
(b)
Top to Bottom Surface Contact of Gel Insole at Forefoot Region

Fig. 2 Loss of gel between top and bottom surfaces at (a) heel and (b) forefoot

RESEARCH QUESTION

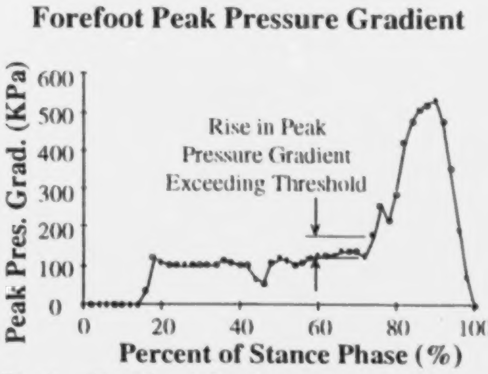
In this investigation, we assessed efficacy of silicone gel-filled shoe insoles for relieving elevated plantar pressures, in a manner consistent with the mechanism by which these gel insoles can relieve plantar pressure (i.e. maintaining nearly uniform pressure within the fluid and transmitting such pressure across the upper surface).

In addition to identifying peak plantar pressures at the heel and metatarsal head regions, our evaluation also involved computation and identification of peak plantar pressure gradients in the heel and forefoot regions, as well as the percentage of stance phase at which forefoot pressure gradients increased most dramatically.

Plantar pressure data was collected with a device that measured pressure directly at the foot/insole interface within the shoe. Such data was believed to be more relevant to our purposes than data collected from a pressure platform.

METHODS

Seven healthy adults (3 males, 4 females, mean age = 26, mean weight = 42 lbs) were recruited for this study from among this institution's graduate student population. We selected, for each subject, appropriate sized pairs of silicone gel-filled insoles (PGB Medical, Inc.), and pressure sensing inserts (PEDAR, Novel, Inc.). The quantity of gel within the gel-filled insoles was proportionally similar for all subjects, relative to shoe size. In order to negate potential effects of different footwear, each subject's shoes and socks were removed, and the pressure sensing inserts were taped directly to the bare plantar surfaces of each subject's feet. For each subject, we obtained pressure data for five steps under each of the following conditions: (1) slow-cadence and (2) fast-cadence while wearing only the pressure sensing insoles; and (3) slow-cadence and (4) fast-cadence with the gel-filled insoles taped over the pressure sensing insoles.



Forefoot Peak Pressure Gradient

Fig. 3 Plot of peak forefoot pressure gradient versus percent of stance phase.

Raw pressure data for each step of every subject was processed using software provided by the equipment manufacturer to obtain peak plantar pressures at the heel and five metatarsal heads (PPH, PPM1, PPM2, PPM3, PPM4, PPM5). For each footwear/cadence combination, peak pressure data at the six regions were incorporated into a euclidean distance-base algorithm to select a representative trial. Each representative trial was processed further using "in-house" software to compute pressure gradients across the plantar surface for each frame of pressure data. Peak gradients at the heel and forefoot regions were identified at each frame; and these data were interpolated to 2% stance time intervals between 0% and 100% (Fig. 3). Overall heel and forefoot peak gradients (PGH and PGF) then were determined for each footwear/cadence combination. Also, the percentage of stance at which forefoot gradients appeared to rise most dramatically (TFGR) were determined by inspection of the interpolated plots (Fig. 3). Consequently, this final parameter was somewhat more subjective than the overall peak gradients. Using a regression technique, a two-way analysis of variance with repeated measures was performed for the parameters identified.

RESULTS

Results of the analysis of variance are summarized in the table below. These results indicate that peak pressures were not affected significantly by either insole use or cadence, except at the heel where peak pressure increased with faster cadence. Peak heel gradients were significantly higher for faster versus slower cadence. Peak heel gradients, however, were not affected by use of the gel-filled insole. Peak forefoot gradients were significantly lower with insole use. Peak forefoot gradients were not affected significantly by cadence. The percentage of stance phase, at which forefoot gradient appears to rise substantially did not seem to be affected by either insole use or cadence.

Table of ANOVA Results:

Effects Relative to no Insole, Slower Cadence

Parameter	Insole	Faster
PPH	N.S.	+42KPa
PPM1	N.S.	N.S.
PPM2	N.S.	N.S.
PPM3	N.S.	N.S.
PPM4	N.S.	N.S.
PPM5	N.S.	N.S.
PGH	N.S.	+65 KPa/cm
PGF	-107 KPa/cm	N.S.
TFGR	N.S.	N.S.

DISCUSSION

The results of this investigation suggest that these silicone gel insoles have little effect on the magnitude of peak plantar pressures, peak heel pressure gradients, or the time of forefoot gradient rise. Use of these insoles, however, does appear to lower peak pressure gradients at the forefoot. Although peak forefoot pressure gradient was the only parameter that was significantly affected by insole use, further investigation of these insoles seems warranted, given that many patients' plantar surface problems occur at the forefoot regions. Future work with these insoles should include use of typical footwear as well as variations in gel fluid volume.

Further study of plantar surface gradients, in general, also should continue since such data have not previously been utilized in investigations of plantar surface loading. Plantar pressure gradients may be useful in studying other orthotic insoles, and may also be valuable for evaluating non-orthotic interventions.

REFERENCES

1. Bordelon RL. Orthotics, shoes, and braces. Ortohopaedic Clinics of North America 1989;20(4):751-757.
2. Boulton AJM, et al. The Prevalence of Symptomatic, Diabetic Neuropathy in Insulin-treated Population. Diabetes Care 1985;8:125-128.
3. Ctercteko GC, et al. Vertical Forces Acting on the Feet of Diabetic Patients with Neuropathic Ulceration. British Journal of Surgery 1981;68:608-614.
4. Holmes GB, and Timmerman L. A Quantitative Assessment of the Effect of Metatarsal Pads on Plantar Pressure. Foot and Ankle 1990;11(3):141-145.
5. Jennings AM, et al. Severe peripheral neuropathy and elevated plantar pressures causing foot ulceration in pituitary gigantism. Clinical Endocrinology 1993;39(1):113-118.
6. Murray HJ, et al. Role of experimental socks in the care of the high-risk diabetic foot. A multicenter evaluation study. American Group for the Study of Experimental Hoisery in the Diabetic Foot. Diabetic Care 1993;16(8):1190-1192.
7. Novick A, et al. Reduction of Plantar Pressure with the Rigid Relief Orthosis. Journal of the American Podiatric Medical Association 1993;83(3):115-122.
8. Pratt DJ. Long Term Comparison of Some Shock Attenuating Insoles. Prosthetics and Orthotics International 1990;14(2):59-62.
9. Sanfillipo PB, et al. Dynamic Plantar Pressure Analysis. Comparing Common Insole Materials. Journal of the American Podiatric Medical Association 1992;82(10):507-513.
10. Schaff PS, and Cavanagh PR. Shoes for the insensitive foot: the effect of a "rocker bottom" shoe modification on plantar pressure distribution. Foot & Ankle 1990;11(3):129-140.
11. Stokes IAF, et al. The Neuropathic Ulcer and Loads on the Foot in Diabetic Patients. Acta Orthopedica Scandinavica 1975;46:839-847.
12. Veves A, et al. Studies of experimental hosiery in diabetic neuropathic patients with high foot pressures. Diabetic Medicine 1990;7(4):324-326.
13. Veves A, et al. Use of Experimental Padded Hosiery to Reduce Abnormal Foot Pressures in Diabetic Neuropathy. Diabetes Care 1989;12(9):653-655.
14. Veves A, et al. The risk of foot ulceration in diabetic patients with high foot pressure: A prospective study. Diabetologia 1992;35(7):660-663.

ACKNOWLEDGEMENT

This work was supported by the National Institute on Disability and Rehabilitation Research (grant #H133E30009).

ADDRESS

Peter M. Quesada, Ph.D.
Ohio State University
1032 Dodd Hall
480 West Ninth Avenue
Columbus, OH 43210
Tel: 614-293-3808 FAX: 614-293-4834
email: Quesada.1@osu.edu

A MANUAL WHEELCHAIR EXERCISE DEVICE WITH POWERED ASSISTANCE

T. Nantais, J. Pepper, E. Aimone, J. Vaughan, M. Plyley & M. Tonack
Lyndhurst Hospital
Toronto, ON, Canada

ABSTRACT

A wheelchair roller with motorized assistance is described. The device is meant to address problems with the use of wheelchair propulsion exercises in the early stages of rehabilitation following spinal cord injury at the C5-C7 levels. A computer monitors the movement of the rollers to provide a record of each exercise session for use in tracking progress and setting goals.

PROBLEM

During the early stages of rehabilitation, many individuals with quadriplegia, who will ultimately use a manual wheelchair, do not have the strength or endurance initially to propel a manual wheelchair over functional distances. As a result, physical exercise sessions in the wheelchair are tiring, short, and frustrating. Wheelchair propulsion exercises are important, however, because they specifically train the muscles required for wheelchair mobility.

RATIONALE

A wheelchair exercise device with a wide range of resistance settings is needed. Many such variable resistance devices have been developed for rehabilitation research in the last ten years [1-7]. Often the objective has been to imitate over-ground wheeling as closely as possible in a stationary situation so that kinematic, kinetic, and physiological measures can be taken. Our objective is different in that we need a device whose resistance can also be set to be less than that of over-ground wheeling. Resistance needs to be precisely adjustable over an interval ranging from near zero to one comparable to a moderate uphill slope. Such a device would retain the necessary exercise specificity while giving the therapist the ability to grade the exercise to suit each client's current physical status.

If the exercise device could also measure a variety of progress indicators, it could be used to address a second clinical problem related to the one above. Clients typically spend weeks at arm exercises before the strength and endurance necessary for wheelchair propulsion develop. Gains can be difficult to notice from one day to the next, and without an objective indication of progress, discouragement and loss of interest can result.

For this reason, computer-based motion measurement and display became an important design objective. Variables that might be useful in tracking progress include exercise time, speed, power, and total work done. Indicators of improved strength and endurance would provide incentive for the exercise, as well as an objective basis for goal-setting.

DESIGN

Past wheelchair exercise devices with variable resistance have been based on a variety of principles. All involve connecting the wheelchair wheels to an external device which can exert a force on the wheels, either through rollers [3,7] or some other mechanical connection such as a chain and sprockets [1,2,4,5,6]. Some devices include an adjustable, permanent seating system. Although there are advantages to this approach in terms of fixing experimental conditions, there are clinical advantages to having each client exercise in his or her own wheelchair. Even very small positioning changes can have a large effect on pushing comfort and effectiveness. For this reason, a roller approach was chosen.

The devices used to generate the resistance have included friction belts [1,6], magnetic braking devices [5,7], motors [2,3], and isokinetic dynamometers [4]. While considering these possibilities for controlling resistance, the idea was put forward that a motor could be connected to supply a constant torque to one of the rollers. Depending on the direction of the torque, the motor would either assist in overcoming the natural mechanical resistance to movement or add to it. This constant but adjustable torque could be delivered if the motor was driven by a voltage-controlled current source. We imagined setting the system up so that a negative control voltage would cause the motor to contribute torque in the same direction that the user is pushing the wheels, while a positive control voltage would make wheeling more difficult (see Figure 1). Such a range of resistances would be likely to meet most clients' needs.

For taking measurements, the first step is a suitable motion transducer connected to one of the rollers. Once connected to the computer, the transducer would provide the signal(s) necessary to calculate speed and distance measures. If the rotating parts do not slip with respect to each other, one roller's speed uniquely determines the speed of the wheelchair wheels.

Differentiating the speed signal to get angular acceleration is one approach to provide a basis for power and work estimates. However, extensive modeling and calibration are required to calculate power from acceleration. The motor's torque contribution is one unknown which varies with control voltage. The friction moments and inertias of the various parts of the system are unknown as

213

well, and these can be expected to change with the user's mass and wheelchair characteristics.

Another possibility for power estimation is through the direct measurement of the user's torque input [2,8]. However, torque transducers are expensive, and a fast but accurate method of connecting the transducer to any number of different wheelchairs would be required for the roller to remain useful in the clinic.

At this writing, we are still looking for an acceptable power measurement scheme. It seems that acceleration measurement and kinetic modeling is the most practical idea, but an acceptable calibration scheme has yet to be developed.

DEVELOPMENT

The prototype is based on a Bug Roller (McLain Cycle Products, Traverse City, MI) which uses two hollow rollers with 4.5 inch diameters. In the normal configuration, a flywheel is connected to one of the rollers by a belt to provide inertia. The flywheel was replaced with a Framco DC motor (24 V, 9 A max.) as shown in Figure 1. The current source chosen to drive the motor (Galil Motion Control Inc., Sunnyvale, CA) accepts a control voltage and produces a proportional current in the range of plus or minus 12 A. The current is controlled with a dial and a built-in meter gives visual feedback of the actual current delivered.

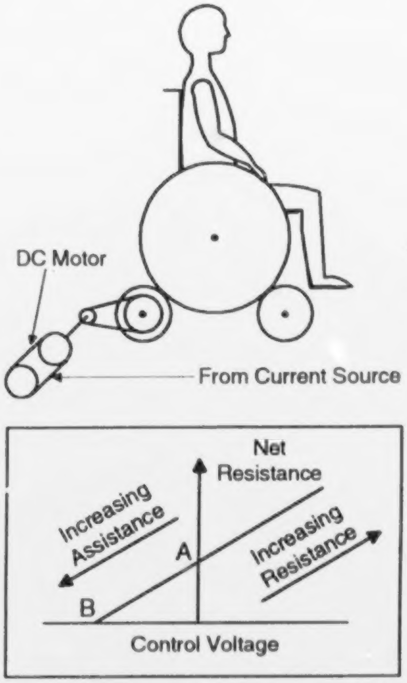


Figure 1: Movement assistance is provided by a DC motor connected to one of the rollers. Inset: the motor's effect on net mechanical resistance. In (A), the motor is not asssisting or resisting and net resistance only depends on friction and rolling resistance. In (B), the motor provides enough torque to balance friction and rolling resistance. At this setting, the wheels take practically no force to turn.

For motion measurement, an optical encoder (Davis Controls, Toronto, ON) was connected to the motor shaft. The encoder produces 1000 TTL-compatible pulses per revolution which provides a theoretical angular resolution of 0.02 degrees on the movement of a 24 inch diameter wheelchair wheel. Because we did not want to waste computer resources counting pulses from the encoder, this task was given to a 80C196KR microcontroller. The microcontroller can be programmed either to count the number of pulses in a given time interval or to measure the time interval between two successive pulses for very precise speed measurements. Its timing resolution is 250 ns.

In normal use, the microcontroller counts the number of pulses coming from the encoder in a fixed time interval and transfers each count to a host computer over an RS232 link. The software running on the host computer calculates speed by first converting the incoming pulse count into the equivalent angular measurement, and then dividing by the microcontroller's sampling interval.

The host software displays speed, session time, and total distance traveled for the user throughout the session. The user sees a strip-chart display of the average wheelchair speed which is updated at 1 second intervals. A bar placed to the left of the strip-chart shows instantaneous speed so that the user can monitor how high the peak speed is going with each stroke. This bar chart is updated 10 times per second. The program also puts raw speed information from the microcontroller into a data file. With this record, any number of performance measures can be compiled at a later date for within-session and between-session comparisons.

EVALUATION

The roller has been in use in the Hospital's Physiotherapy Service for eight months. In that time, five individuals with quadriplegia (ranging from C5 to C7) have trained on it. Although empirical evidence of the roller's effectiveness as a treatment tool will be the subject of future work, the participants so far have expressed satisfaction with their progress while exercising on it. They find the total distance traveled useful for comparing their performance against previous sessions. However, they realize that this comparison is only valid when the same motor torque is used in each session.

Figure 2 is an example of the type of information that can be obtained from the raw data files. The graph shows the changes in average speed during an exercise session on the roller completed by an individual with a C5-incomplete spinal injury. At the time of the session, the client was not using a manual wheelchair except in physiotherapy. The therapist's instructions were to wheel at a comfortable pace for ten minutes, taking breaks

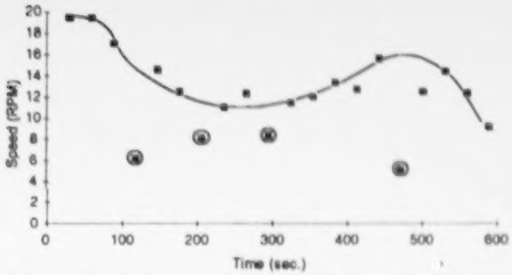


Figure 2: Average wheel speed taken at 30 second intervals for a typical ten-minute exercise session. The four circled outliers contain rest periods.

whenever necessary. The motor delivered a moderate level of assistance throughout. During the first three minutes, the average speed dropped by approximately 35%. This decrease, along with the four rest periods taken, demonstrate the effect of fatigue on performance. The client and therapist can compare similar charts from future sessions to see if this speed decrease becomes less pronounced with training.

DISCUSSION

Exercise specificity is an important consideration in wheelchair propulsion training [9]. A roller with powered assistance makes wheelchair-specific exercise possible at an earlier point in rehabilitation. The wide range of available motor torques gives the therapist freedom to tailor training protocols both to the different stages of rehabilitation and to the specific needs of each client. For example, training with progressive overloading becomes possible even at a stage when a client might be unable to move the wheels while on a conventional roller.

The development of this device as a training and testing tool is at an early stage. The most pressing need is to develop a reliable power measurement. The ability to gauge the client's power input independent from the motor's contribution is necessary for between-session comparisons involving different assistance levels. Power measurement is also required for the development of alternative testing protocols and research into physiological variables important in early spinal cord injury rehabilitation.

In the future, the system could be used to find ways to make the wheeling exercise more interesting. If the computer could control the motor, for example, standard training courses with simulated hills would be possible. While exploring these options, we hope to continue to use the device in the clinic as an additional source of objective information, and increasingly as a source of novelty for wheeling exercise.

ACKNOWLEDGMENTS

This project was supported by The Lyndhurst Hospital Foundation, The Westin Foundation, and private donation. We are grateful for equipment donations from Motion Specialties, Everest and Jennings Canadian Ltd., and IBM Canada Ltd. We would also like to acknowledge John Hancock for mechanical construction of the prototype, and Kevin Day for software programming.

REFERENCES

[1] Glaser, R. (1989). Arm exercise training for wheelchair users. *Med. Sci. Sports Exerc.*, 21(5) (suppl.) S149-S157.

[2] Niesing, R., Eijskoot, F., Kranse, R. den Ouden, A.H. et al. (1990). Computer-controlled wheelchair ergometer. *Med. & Biol. Eng. & Comput.*, 28, 329-338.

[3] Coutts, K.D., Rhodes, E.C., & McKenzie, D.C. (1983). Maximal exercise responses of tetraplegics and paraplegics. *J. Appl. Physiol.: Respirat. Environ. Exercise Physiol.*, 55(2), 479-482.

[4] Samuelsson, K., Larsson, H. & Tropp, H. (1989). A wheelchair ergometer with a device for isokinetic torque measurement. *Scand. J. Rehab. Med.*, 21, 205-208.

[5] Paré, G., Noreau, L., & Simard, C. (1993). Prediction of maximal aerobic power from a submaximal exercise test performed by paraplegics on a wheelchair ergometer. *Paraplegia*, 31, 584-592.

[6] Wicks, J.R., Oldridge, N.B., Cameron, B.J. & Jones, N.L. (1983). Arm cranking and wheelchair ergometry in elite spinal cord-injured athletes. *Med. Sci. Sports Exerc.*, 15(3), 224-231.

[7] Langbein, W.E., Robinson, C.J., Kynast, L. & Fehr, L. (1993). Calibration of a new wheelchair ergometer: The wheelchair aerobic fitness trainer. *IEEE Trans. Reh.*, 1(1), 49-57.

[8] Asato, K.T., Cooper, R.A., Robertson, R.N. & Ster, J.F. (1993). SmartWheels: Development and testing of a system for measuring manual wheelchair propulsion dynamics. *IEEE Trans. Biomed. Eng.*, 40(12), 1320-1324.

[9] Glaser, R.M., Sawka, M.N., Durbin, R.J., Foley, D.M. et al. (1981). Exercise program for wheelchair activity. *Am. J. Phys. Med.*, 60, 67-75.

CONTACT

Tom Nantais
Research Department
Lyndhurst Hospital
520 Sutherland Dr.
Toronto, Ontario, Canada
M4G 3V9

voice: (416) 422-5551 x. 3049
fax: (416) 422-5216
E-mail: 74267.2252@compuserve.com

SIG-06
Special Education

MULTIMEDIA FOR ASSISTIVE TECHNOLOGY TRAINING AND RECRUITMENT: TWO CD-ROM TRAINING PROGRAMS

Jo E. Fleming and Bernard P. Fleming
University of Kentucky
Lexington, KY 40502

ABSTRACT

CD-ROM interactive multimedia is proving to be an effective method for training in special education and rehabilitation. Two computer programs that employ interactive multimedia to provide awareness about the uses of assistive technology by persons with disabilities are being developed. The first program, *Guide to Assistive Technology Experiences (G.A.T.E.)*, features six individuals who successfully use assistive technology to assist them in the functional areas of daily life. The second program, *Forrest Centerstage*, is an interactive storybook about a student with physical disabilities and his use of assistive technology. Both programs feature assistive technology, but the formats for presentation differ significantly.

BACKGROUND

Recent federal, state, and local initiatives have resulted in increasing numbers of children with disabilities being educated in general education classes with their non-disabled peers. One of the facilitating factors for inclusion is the availability of assistive technology devices that allow students with disabilities to achieve the same instructional objectives as their non-disabled peers. While some special educators are aware of these devices, other educators and parents do not realize that these products exist and that schools are required to make them available if the products will help children accomplish the goals specified in their I.E.P.s.

STATEMENT OF THE PROBLEM

Many special education teachers, parents, speech/language pathologists, occupational therapists, physical therapists, and other education and rehabilitation personnel could be more effective in their instructional programming with children with disabilities if they had expanded information about the existence and potential of assistive technology. Professionals and students in other fields, such as medicine, engineering, and computer science might become interested in the area of assistive technology if they were only aware of its benefits.

RATIONALE

Multimedia is an effective way to present detailed information about the enormous range of available assistive technology for people with disabilities. CD-ROM technology allows the components of video, sound, animation, still photography, text, and other graphics to be presented in an entertaining, yet informative manner. The number of multimedia computers in schools, universities, businesses and homes is growing continually and encourages use of CD-ROM as an effective method of delivery.

DESIGN

Two CD-ROM programs have been developed. Although the basic objective is the same in both programs - to provide awareness training on the uses of assistive technology for people with disabilities, the formats differ significantly.

G.A.T.E. To provide assistive technology awareness training to preservice and inservice special education and related service personnel, an interactive multimedia CD-ROM program has been developed.

Forrest Centerstage. To enhance awareness of the uses of assistive technology in a format that is entertaining to children, an interactive CD-ROM storybook has been developed.

DEVELOPMENT

Guide to Assistive Technology Experiences (G.A.T.E.) is an interactive multimedia program stored on a CD-ROM disc for Macintosh computers It will also be formatted for systems running Windows. The program was developed by personnel in the Department of Special Education at the University of Kentucky to assist in training and recruitment concerning assistive technology. This program features six individuals who are successful users of assistive technology. These individuals represent age groups of pre-school, elementary school, secondary school, post-secondary school, adult-working, and elderly adult. They are influenced by physical, sensory, and cognitive disabilities. Assistive technology assists them across the functional areas of self-help; communication; body support and positioning; travel and mobility; environmental adaptation; education; and sports and recreation.

This multimedia program introduces each individual in a video segment. The user can then obtain more information about each individual through a menu of these options: assessment procedures for assistive technology, professionals involved with the individual, other assistive devices used by the individual, funding for assistive technology, and uses of assistive technology by other individuals in the same age group or for the same functional areas. Along with QuickTime video clips, the program contains narration, still photography, animation, graphics and text. A glossary of assistive technology terms is always available. Assistive technology used successfully in real-life situations is demonstrated.

Forrest Centerstage is also a CD-ROM based interactive multimedia program about assistive technology. As the intended audience, this program targets students with disabilities, their parents, their non-disabled peers and the professionals who work with them. The format is an interactive storybook - an illustrated children's book was created concerning a child with physical disabilities and his use of assistive technology in his daily life at home, at school, and in the community. When each screen (page of the book) appears, the story is narrated and then the user can "explore" the illustration. When objects are selected, animation, sound, and video demonstrate the use of various assistive devices. Alternate methods of selection have been incorporated into the program.

EVALUATION

Guide to Assistive Technology (G.A.T.E) is currently undergoing field testing for content and format.

Forrest Centerstage has undergone two phases of evaluation. The first, an initial reaction survey was completed by students and professionals from the field of assistive technology. Reactions assisted the development team in making modifications to the final version. Forty-five individuals participated in the final field test. They interacted with the program and completed questionnaires designed to obtain information about content and format. Results indicated that the program was entertaining, informative and would likely have commercial potential.

DISCUSSION

These two interactive multimedia programs about the uses of assistive technology should be beneficial for training in university programs, school system inservice, state Tech Act projects, Alliance for Technology Access Centers, and agencies responsible for implementing the Americans with Disabilities Act. Students and professionals in the areas of special education, speech and language pathology, occupational and physical therapy, engineering, computer science, medicine, and rehabilitation counseling should find the programs of benefit as well. Recruitment into fields related to assistive technology is another intended use of these programs.

Forrest Centerstage is designed to encourage inclusion of students with disabilities in general education programs. Through interaction with the program, students with disabilities and their non-disabled peers will be entertained and also informed about how assistive technology can enable students with disabilities to participate in daily activities.

ACKNOWLEDGMENTS

Funding for the *Guide to Assistive Technology Experiences* was provided by a grant from the United State Department of Education, Office of Special Education Programs.
Funding for *Forrest Centerstage* was provided by grants from the National Institutes of Health, SBIR Program and from the Kentucky Cabinet for Economic Development: Business and Technology Branch to ORCCA Technology, Inc.

Jo Fleming, Ph.D.
Department of Special Education and Rehabilitation Counseling
229 Taylor Education Building
University of Kentucky
Lexington, Kentucky 40506-0001
(606) 257-1520

Interface Specification for Children with Severe Physical Disabilities using Robotics or Other Assistive Technology

Carol A. Stanger
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

Richard D. Howell
Department of Educational Services and Research
The Ohio State University
Columbus, Ohio USA

Abstract

Assistive Technology contributes to the provision of an equal opportunity education for children with severe physical disabilities. Selecting the appropriate technology and the optimum means for activating an assistive device is a complex process which requires understanding many aspects of the child's ability and the resources available to him or her. This paper is a case study of how a comprehensive assistive technology protocol facilitated the selection of an interface for a robotic system with a young man who has a physical disability and is in a mainstream junior high school. By selecting a method of interaction for the robot which built upon his previous experience with assistive technology, he was able to successfully execute tasks with the robotic system the first time that he was introduced to it. Integrating assistive devices into the classroom and the academic learning environment can be facilitated by following a comprehensive protocol with contributions from all members of the individual's team.

Background

Children who are severely physically disabled are at an academic disadvantage when they are unable to act on their environment as their able-bodied piers do. Assistive Technology assists in providing an equal opportunity education by allowing a child who has a disability to have an opportunity to exert control over their environment, thus taking a more active role in the education process. For instance, an electric wheelchair provides mobility, an augmentative communication device invites verbal and social interaction, computer access can provide written communication and alternative interaction strategies for learning, and robotics could provide physical manipulation of objects. The robotically-aided science education project being conducted at the Ohio State University and Applied Science Engineering Laboratories of the A.I. duPont Institute and University of Delaware is developing a prototype system which will allow children with severe physical disabilities to conduct hands-on science experiments with the assistance of a robot [1, 2, 3].

The robotic system is built from off-the-shelf hardware, software, and standard assistive technology interfaces so that focus can be applied to developing an integrated system. The robotic arm being used for this project is the RTX robot. Control for the RTX is provided through a DOS based computer. The software language is the Cambridge University Robot Language, abbreviated CURL, which operates in the Microsoft Windows environment [4]. Commercially available assistive technology systems including the WiViK on screen keyboard with the Prentke Romich Switch Box and the IntelliKeys expanded keyboard are used to provide alternative input to the computer for activating the robot. The science curriculum, which is under development, will specify hands-on science experiments that will be pre-programmed into the robotic system. The child will then be able to command the robot, using assistive technology interfaces, to carry out the particular science laboratory experiment that he or she is unable to conduct independently [3].

Individuals who have a need for this level of assistive technology intervention, by definition, have limited means for interacting with the technology which facilitates their being active in the classroom. There is very little literature and there are few system models on intervention for individuals with severe physical disabilities [5]. Even for able-bodied children, little is known about developmental issues involved in designing computer interfaces [6]. For children with severe physical disabilities, the interactive strategies for assistive technology are as unique as the individuals who need them. However, the interface issues for such children can be addressed in a systematic, comprehensive approach which helps to streamline a difficult process.

Objective

A severely physically disabled child who has reached the public school system already has a history of intervention and techniques for interacting with the world, some of which have succeeded and others that have failed. Family members, aides, clinical health care professionals, school personnel including teachers, therapists, and assistive technology specialists, and the child himself or herself all hold valuable pieces of knowledge, all of which contribute to the assistive technology puzzle. In order to address an interface solution for a child using a robotic interface, the technology research team must rely on the expertise of those who know the child well. To develop appropriate interface technology, the research team benefits from knowing the physical abilities of the individual along with academic status, past experience with a computer or other technology, and seating, positioning, and mobility issues. It is important to know what has been tried and what has not - what has been successful, and what has not. There is no "right" or "wrong" regarding the child's status and access to technology. There is simply an opportunity to make changes for the future.

Approach

At the Delaware site, the robotic work station is targeted for placement in a mainstream junior high school for use by an individual who has cerebral palsy. In order to determine the appropriate interface design for this person to use when interacting with the robot, the researcher met with the family, aide, school professionals, and the young man to collectively fill out a profile describing his abilities. The protocol used was the commercially available, Lifespace Access Profile, which is a 59 element questionnaire that asks the group to identify the individual's current level of available physical, cognitive, emotional, and technology resources. Each of the 59 areas is given a score on a scale of 1 to 10. Physical resources include questions about health, vision, hearing, tactile sensation, muscle tone, coordination, primary and secondary switch access sites, current switch use, mobility, and computer access. Cognitive resources include the reference system for making choices, receptive communication for instruction, expressive communication, academic skills, and computer skill level. Emotional resources include attention span, distractibility, tolerance for frustration and change, initiation of interactions and activities, and academic motivation levels. Technology support resources include the home, educational or training program, and community. All scales are summarized on a single chart at the end of the profile. The profile takes about an hour to complete.

Results

After meeting with the team, the researcher had a comprehensive picture of the individual's past experience with assistive technology. It was known that the young man had successfully used an augmentative communication device about three years earlier and operated it with auto scanning, using a single switch at his left knee. It was also known that the young man currently plays interactive CD games using a Philips Roller Controller (available from Sears) and activates the switches with his left or right fist. It was noted that high switch durability is important. It was also discovered that he had tried operating an IntelliKeys keyboard with his elbow, under the supervision of his physical therapist, but that this interaction was found to be very tiring. We learned that he is highly motivated academically and that his academic reading and science skills are within the level of ability required for successful interaction with the robotic system. It was specified that a DOS based lap top computer was on order for him and that he intended to interact with it using scanning by way of a single switch at his left knee. And finally, it was noted that his current seating system is inadequate and that he uses no assistive technology within the school environment.

This information immediately identified several parameters which were addressed by the research team when setting up the robotic system for this young man for the first time. The type of interface and the interaction strategy was set up so that his chances for a successful interaction were optimized. The robotic interface which was presented to the young man was a customized WiViK on screen keyboard activated by auto scanning from a single switch at his left knee. Direct robot motions were operated with single switches by way of his right and left hands. His first interaction with the robot was the most successful of any child who had used the system to date. The success of the interaction was largely attributed to the fact that the interaction strategy was assembled for his personal knowledge base. Because we knew that he had used scanning before, we were able to presume that he understood the concept behind the technique. The technique did not have to be taught to him. He only needed to learn what the specific commands meant within the robotic interface context. In addition, we used a scanning format that he had used before, automatic row-column. There are many scanning formats available under WiViK, but using one that he was familiar with made our set-up decisions easier and his interaction more successful than it might have been otherwise. We used switch access sites which had a high probability for success. By doing so, we were able to have him successfully interacting with the system in minimal time. We then had the ability to systematically make modifications to improve his rate of interaction. For instance, during the first session, we started with Able Net Jelly Bean switches in a two switch holder to directly move the robot. He then tried plate switches from TASH, that were attached by velcro to the table-tray, which he found to be a better way of activating the robot. From this point, we can continue to make modifications to the system during future visits and continue to improve the interaction strategy without questioning his ability to accomplish the task. Once the interface is refined, we can introduce conceptually difficult learning tasks which then challenge only his academic abilities, not his ability to learn how to use the system.

Discussion

Assistive technology is one of the tools available for providing children who have severe physical disabilities with an equal opportunity education. A comprehensive and honest evaluation of each individual's physical, cognitive, emotional and technology resources by the team of individuals who know the child best, provides a road map for selecting the technology that can be most effective for learning. There is a learning curve for all technology use. Some systems, like a robotic device, require more learning than others. However, if the assistive device is introduced in a way that builds on the child's past successes, either with other technology, particular learning styles, or topics which are highly motivating for that individual, the focus on technology is decreased, and the benefits of using the technology for academic learning is increased. By having a profile of the child and his or her available resources, focus can be directed to those areas which are in need of attention. For instance, the Lifespace Access Profile indicated that the school personnel had few technology resources. Consequently, when the robotic system is placed into the school environment, the researchers know in advance that training and technology support will be critical for successful integration of the robotic system into the school environment. In a different school, this resource may be adequate, but there will be other areas that need attention. Conducting a profile of the child not only indicates a current direction for assistive technology selection, but can also serve a a means for monitoring the progress of the individual from year to year.

References

[1] Beitler, M.T., C.A. Stanger, R.D. Howell, "The Design of an Integrated Interface to an Educational Robotic System" RESNA Proceedings, 1994, p. 448-450.

[2] Howell, R., C. Stanger, B. Chipman, "Robotically-Aided Science Education for Children with Disabilities", International Conference on Rehabilitation Robotics, June 1994, p. 165-168.

[3]Howell, R., C. Stanger, S. Martz, B. Chipman, "The Development of a Robotically-Aided Science Education Laboratory for Inclusive Classrooms", RESNA Proceedings, 1995.

[4]Dallaway JL, Mahoney RM, Jackson RD (1993) CURL - A Robot Control Environment for Microsoft Windows. RESNA 93 - Proceedings, 510-511.

[5] Hussey, S.M., A.M. Cook, S.E. Whinnery, L. Buckpitt, M. Huntington, "A Conceptual Model for Developing Augmentative Communication Skills in Individuals with Severe Disabilities", RESNA Proceedings, 1992, p. 287-289.

[6] Revelle, G.L., Strommen, E.F., "The Effects of Practice and Input Device Used on Young Children's Computer Control", Jl. of Computing in Childhood Education, 2(1) Fall 1990, p. 33-41.

IntelliKeys is available from IntelliTools, Inc. of Novato, CA.

Jelly Bean switches are available from Able Net of Minneapolis, MN

Lifespace Access Profile is available from Lifespace Access of Sebastopol, CA

Plate Switches are available from TASH of Ontario, Canada

WiViK is available from Prentke Romich Company of Wooster Ohio.

Windows™ 3.1 & Microsoft® are registered trademarks of Microsoft Corporation

Acknowledgments

This research is supported Grant Number H133E30013 from the National Institute on Disability and Rehabilitation Research (NIDRR). Additional support has been provided by the Nemours Foundation.

Special thanks to those who are associated with the Delaware junior high school who have taken part in the educational robotic system development.

Author address

Carol Stanger
Applied Science & Engineering Laboratories
A.I. duPont Institute
Rehabilitation Engineering Research Center in Rehabilitation Robotics
P.O. Box 269
Wilmington, DE 19899

stanger@asel.udel.edu

DOCUMENTING ASSISTIVE TECHNOLOGY USE IN FLORIDA

Sandra Osborn, Katherine George, Beverly Fraser (Consultant)
Assistive Technology Educational Network of Florida
434 North Tampa Avenue, Orlando, FL 32805

ABSTRACT

An Assistive Technology Educational Network of Florida (ATEN) pilot study develops and field tests a method for documenting success achieved in device use by selected students from multiple school sites in Florida. Sixteen students with disabilities are included in this study. Students use high and low tech devices and are of various ages and functioning levels. The study focuses on a) documenting individual student performance using an assistive technology device over time and across settings and b) obtaining opinions of the student, the student's parents, and school staff regarding this experience. Coupling of student performance and consumer opinion is a unique study feature. The pilot study represents an important first step in addressing accountability issues.

BACKGROUND

Assistive technology has become a powerful enabling force central to the lives of many students with disabilities.[1] Benefits of assistive technology device use extend to multiple environments and allow participation in educational, home, community, work, and recreational settings.[2] ATEN provides information and training about assistive technology and loans devices for assessment. ATEN's staff identified a need to develop a systematic method of documentating student performance using an assistive technology device.

STATEMENT OF THE PROBLEM

Assistive technology is expensive. Time and labor-intense interdisciplinary assessment is required prior to prescription of a device appropriate for an individual student. Devices range in price from $250 to over $5,000. Once a student receives a personal device, extensive training is provided and must be repeated, at least in part, when a school or staff change occurs; when a student progresses and needs to learn expanded use of a device; or when a student is upgraded to a new device.

While assistive technology is recognized as crucial for students with disabilities, little has been done to document student progress using specific devices.[3-6] Yet, documentation of student performance is needed to satisfy educational and cost accountability considerations.

APPROACH

This pilot study develops and field tests a method for documenting success achieved in use of assistive technology devices. The study focuses on a) documenting individual student performance using an assistive technology device and b) obtaining opinions of the student, the student's parents, and school staff regarding this experience.

Student performance is documented over time and across settings. Data is obtained during baseline (first five trials) and training phases. Time requirements for the training segment are determined on an individual basis, with a minimum of four weeks training (containing 15 or more sessions). Two aspects of student performance using a specific assistive technology device are documented: a) device operation (skill in using the device) and b) success in device application toward a defined goal. For each aspect, measurable outcomes are defined by school staff. Data analyses for each performance includes graphic representations, comparison of performance range and mean based on five baseline trials and the last five device uses during the training segment, and comparison of student performance versus staff's expectation. Inter-observer agreement is based on video tape recordings of student performance.

Students, parents, and school staff express their opinions on specially developed questionnaires requiring either a yes or no response. Separate, but parallel, questionnaires are completed after baseline and after training to provide a means of determining opinion change trends. In addition, education professionals involved rate various aspects of this documentation method according to values expressed as "excellent", "good", "fair", "marginal", or "none". Study participants' comments are recorded and analyzed for commonalities.

IMPLICATIONS

Student use of assistive technology is highly individualistic. The documentation method developed via this pilot study only evaluates individual student performance. Findings for each student will constitute a progress report. Such findings are not usable as predictors of future performance and should not be generalized to populations. However, this documentation method produces strong evidence of individual performance success, a basis for analyzing student performance, and a means of focusing device use toward defined goals and coordinating device use across settings.

DISCUSSION

Coupling of student performance and consumer opinion is a unique study feature. Literature reviews reveal no studies that document assistive technology device use coupled with consumer opinion information. The concept of measuring student performance over time and across settings is based on single-system research designs.[7] However, designs are modified for this study. Opinions of students with disabilities using devices, along with those of their parents and school staff, represent an important aspect of this study. Experience suggests that success in device use is influenced considerably by the satisfaction level of students, school staff, and parents.[8] Failure to consider consumer opinion of assistive technology devices can lead to equipment abandonment and wasted training efforts.[9]

Clearly, documentation of assistive technology use by students with disabilities is in a preliminary stage. ATEN's pilot study represents a pioneering effort that provides direction for future study.

REFERENCES

1. Daniels, S. M. (1990) The meaning of disability: Evolving concepts. Assistive Technology Quarterly,Fall, 6-7.
2. Williams, W. B., Stermach, G., Wolfe, S., & Stanger, C. (1993). Lifespace access profile: Assistive technology planning for individuals with severe or multiple disabilities. Sebastopol, CA: Lifespace Access, 2.
3. Todis, B., Walker, H.M. User perspectives on assistive technology in educational settings. Focus on Exceptional Children, 1993:26:3:1-15.
4. Leading and managing for performance. An examination of challenges confronting special education. Alexandria VA: National Association of State Directors of Special Education, Inc. 1993.
5. Trachtman, L. Outcome measures. Are we ready to answer the tough questions? Assistive Technology, 1994:6.2:91-92.
6. Goodenough-Trepagnier, C. Design goals for augmentative communication. Assistive Technology, 1994:6.1:3-9.
7. Ottenbacher, K. J. (1986). Evaluating clinical change: Strategies for occupational and physical therapists. Baltimore: Williams & Wilkins, 197.
8. Phillips, B., & Zhao, H. (1993) Predictors of assistive technology abandonment. Assistive Technology, 5, 36-45.
9. Grady, A., Kovach, T., Lange, M., & Shannon S.. (1991). Promoting choice in selection of assistive technology devices. In: Proceedings of the Sixth Annual Conference on Technology and Persons with Disabilities (pp. 315-22). Los Angeles: California State University, Northridge.

ACKNOWLEDGEMENTS

This publication was developed through the Assistive Technology Educational Network of Florida (ATEN), Florida Diagnostic and Learning Resources System (FDLRS) Specialized Center, Orange County Public School, funded by the State of Florida, Department of Education, Division of Public Schools, Bureau of Student Services and Exceptional Education under the Individuals With Disabilities Act (IDEA), Part B.

Ms. Sandra Osborn
Assistive Technology Educational Network
of Florida
434 North Tampa Avenue
Orlando, FL 32805
Phone: (407)328-3678 Fax: (407) 849-3518

THE USE OF SELF OBSERVATION VIA AUDIOTAPES AND COMPUTER SPREADSHEETS TO IMPROVE ORAL READING

Al Cavalier and Bernadette Gilmore
Department of Educational Studies
University of Delaware
Newark, DE 19716 USA

ABSTRACT

The purpose of this study was to evaluate the effectiveness of a treatment package in remediating oral reading problems in a student with learning disabilities and attention deficit disorder. The primary components of the package consisted of modeling, guided self observation, and computer graphing. This study employed a changing criterion single-subject research design. Results indicated that the treatment produced significant improvements in oral reading accuracy. Interpretations are discussed.

BACKGROUND

Because oral reading is frequently required in regular elementary classrooms, oral reading proficiency is viewed by many professionals as a "survival skill" for students with learning disabilities in inclusive settings (4). Much of the recent research on oral reading focuses on identifying the best methods for reducing the cognitive effort and increasing the automaticity of the decoding process (3).

Reitsma (3) compared the effects of guided reading, reading along, and speech-select reading. The guided reading group read stories out loud, receiving clues from the teacher when needed. The reading along group read stories silently while listening to an audiotape. The speech select group could request a spoken version of any unknown word by touching the word as it was presented on a Power Pad that was interfaced to a computer with speech output. The subjects were first grade students. Each of 20 target words were incorporated into five short stories of about 250 words in length. Students in the guided reading and speech select conditions improved in reading rate more than those in the read along and control conditions. In accuracy, the guided reading group improved the most. The author concluded that it was the active participation of the students in the activity that gave the guided reading and speech select conditions the advantage over simple repeated exposure.

Rasinski (2) criticized the Reitsma study because the critical feature of the read along strategy, repeated practice on the same text, was not incorporated. Rasinski compared repeated reading and reading-silently-while-listening using third grade students with varied reading abilities. First, half of the subjects practiced reading aloud a 100-word passage at the fourth grade level. The other half read the passage while listening to a audiotaped rendition. Next, the treatment was reversed for each subject. Gains in accuracy and speed for both methods were comparable. Rasinski believes that the success of the read along strategy in his study affirms the importance of the teacher modeling fluid reading for students and suggests that this strategy may have an advantage over repeated reading because it is less labor intensive for the teacher when audiotapes are used.

The present study sought to build on this existing research by adding to the modeling technique new components designed to increase the student's attention to key elements in the task and to improve his motivation to succeed. These components were guided self observation, consisting of audiotapes of the student himself along with written and oral corrective feedback from the experimenter, and computer graphing, consisting of visual displays of the student's performance administered contingently for improved reading. We hypothesized that this treatment package would be effective in remediating longstanding problems in oral reading.

METHOD

Subject. The subject was an 11 year-old boy who was diagnosed with learning disabilities and attention deficit disorder. He was receiving full time special education services in a self-contained classroom in a suburban elementary school. He was also taking Ritalin and Clonidine. His oral reading skills were highly inconsistent. He exhibited sequencing problems and attention problems that interfered with his reading. These problems were exacerbated when words were presented in a story format, as opposed to single word presentation. The study was conducted in the subject's home three times a week in mid-afternoon.

Target Behavior. The target behavior was oral reading accuracy when reading sentences. Accuracy was defined as complete and correct pronunciation of the words presented. Omissions, substitutions, additions, reversals, and mispronunciations were considered inaccurate. Self corrections within five seconds were viewed as accurate. A tape recorder was used to record each session. Data storage and graphing were performed on a Macintosh computer using the Microsoft Excel spreadsheet program.

Experimental Design. The changing criterion single-subject experimental design was used (1). This design can evaluate systematic, stepwise increases in performance. The design consists of two phases, a baseline and a treatment phase. The treatment phase is divided into various subphases, each with a greater criterion for success than the preceding one. The subject progresses to the next criterion (subphase) if he meets the current one during three consecutive sessions. Support is obtained for the existence of a functional relationship between the treatment and improvement in the subject's performance when the subject meets the criteria of three consecutive subphases.

Procedure. Baseline performance was determined by administering five pretests. During each pretest, the subject was presented with a 50-word first grade passage from the book, *Smiles*, in the Harcourt Brace reading series. Passages were presented on index cards, one sentence per card. The subject was instructed to read the sentence aloud. If he came to a word he did not know, he was instructed to make a guess. The number of words correctly read served as his baseline performance.

At the start of each treatment session, the subject was told the goal (criterion) of the session (a specific number of words read correctly) and that if he met the goal he could enter the number of correctly read words into his computer and print out a graph of his performance. The accuracy criterion for each subphase was based on his performance during the previous subphase. When he met the criterion for three consecutive sessions, a new subphase and criterion were established. The terminal criterion was set at 94% (47) of the 50 words.

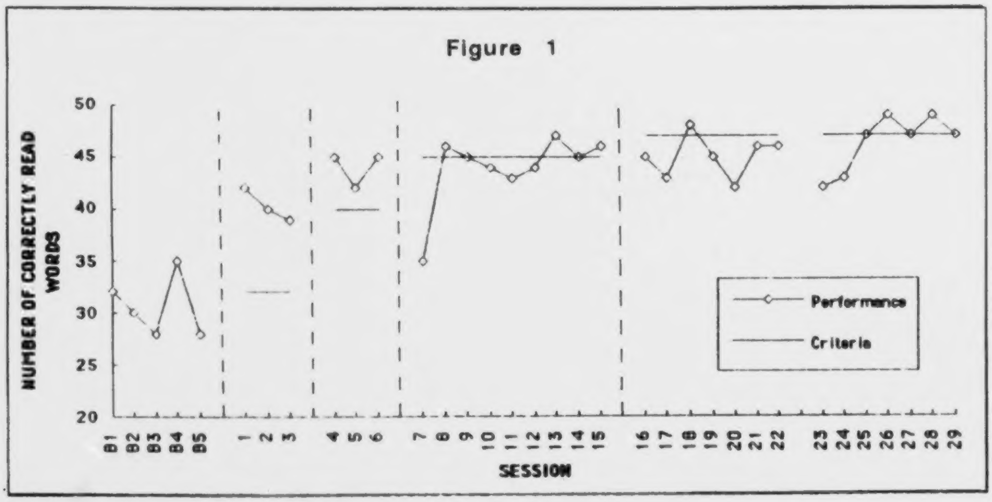
The treatment consisted of five components. First, a complete 50-word passage was read aloud to the subject. He was instructed to listen while reading silently from a printed copy of the passage. Second, the passage sheet was removed, and he read the passage aloud as it was presented to him one sentence at a time on index cards. The experimenter underlined on the printed passage sheet any words that were incorrectly read. His reading was tape recorded. Third, the subject listened to himself on tape while he read silently along on the underlined passage sheet. The tape was stopped after every sentence. If it was an errorless sentence (no words underlined), the subject was praised. If it was a sentence with errors, the subject reread the sentence aloud. For any error that he did not spontaneously correct during this rereading, the experimenter read the word correctly and then the subject did the same.

Fourth, at the end of the session, the accuracy data were counted by the subject and the experimenter together. If his performance met the criterion, then the subject was permitted to go to the computer, open his spreadsheet file, enter the new data, and print out the graph. The experimenter then focused discussion on his performance relative to the criterion, e.g., "This is the second day that you were above the mark!" If the subject did not meet the criterion, he was so informed and told that he could try again tomorrow.

It was observed that the subject was having particular difficulty reading words ending with "ed". As a result, a fifth treatment component was added to the final seven sessions. A set of six words ending in "ed" was presented for practice before starting the normal routine. The words were chosen from that day's reading passage Each word was presented individually to the subject. The experimenter read aloud the word and then the subject read aloud the word. If he made an error, the process was repeated until he read the word correctly. The subject was then asked to read the complete list. The process continued until he read the list with 100% accuracy two consecutive times.

RESULTS AND DISCUSSION

The subject averaged 30.6 correct words out of 50 across the five baseline pretests. During the treatment phase, his performance resulted in four subphases. The respective criteria for these subphases were 32, 40, 45, and 47 words read correctly. The results are depicted in Figure 1. The subject exceeded the first criterion on each of the first three treatment sessions, averaging 40.3 words per session. He exceeded the second criterion on each of the next three sessions, averaging 44 words per session. He required six sessions of treatment before meeting the third criterion on three consecutive sessions. The terminal criterion was



very difficult for him to achieve. His scores did not improve after seven sessions. An error analysis revealed that attempting to decode words ending in "ed" was largely responsible for this difficulty. To assist him in overcoming this final challenge, a fifth component was added to the treatment (described above). After two sessions of this modified treatment, the subject met the terminal criterion on five consecutive sessions.

The guided self observation component appears to have been informative to the subject. His interest seems to have been piqued by hearing his own voice and this may have made more salient to him the decoding elements that were problematic. He tried very hard to*not* repeat any errors that he was able to perceive on his tape. This often resulted in spontaneous self-corrections. His motivation to read correctly, however, seemed especially heightened by the reward of entering his own data into the computer spreadsheet and watching it graph the results. This component seemed to capitalize on the fascination that computers typically hold for children while also enhancing his self esteem. The computer graph appeared to act as a cognitive aid, making concrete for him his level of accomplishment and providing an extended and permanent record of his progress.

These data provide strong support for the conclusion that the treatment package consisting of teacher modeling, guided self observation, and computer graphing was effective in remediating longstanding problems in oral reading accuracy. The evidence suggests that the added component of individualized practice on the subject's most difficult decoding problem was responsible for additional improvements. The instructional and motivational power of both guided self observation and computer graphing warrant further exploration with students with learning disabilities.

REFERENCES

1) Hartmann, D. P., & Hall, R. V. (1976). The changing criterion design. *Journal of Applied Behavior Analysis*, *9*, 527-532.

2) Rasinski, T. V. (1990). Effects of repeated reading and listening-while-reading on reading fluency. *The Journal of Educational Research*, *83*, 147-150.

3) Reitsma, P. (1988). Reading practice for beginners: Effects of guided reading, reading-while-listening, and independent reading with computer-based speech feedback. *Reading Research Quarterly*, *23*, 219-234.

4) Rose, T. L., & Beattie, J. R. (1986). Relative effects of teacher-directed and taped previewing on oral reading. *Learning Disability Quarterly*, *9*, 193-199.

Al Cavalier 302-831-6309
cavalier@strauss.udel.edu

BEST COPY AVAILABLE

SIG-07
Technology Transfer

ADVANCED WHEELCHAIR ELECTRONICS CONTROLLER: A PRELIMINARY PILOT EVALUATION REPORT

Saleem J. Sheredos, Mary E. Cupo, Department of Veterans Affairs, Rehabilitation R&D Service, Technology Transfer Section, Baltimore, Maryland
Leonard Anderson, Andy Stallard, Daniel M. Carney, Rehabilitation Engineering Center, Wichita, Kansas

ABSTRACT

The Advanced Wheelchair Electronics Controller (AWEC) is the result of research and development conducted under the direction of Leonard Anderson, MS, at the Daniel M. Carney Rehabilitation Engineering Center. Funding for this R&D effort was provided through the Cerebral Palsy Research Foundation, Wichita, Kansas. The AWEC was developed to provide power wheelchair users and clinicians with a controller that allows adjustability of operating parameters, interchange of input options, and retrofit for use on any power wheelchair (with two good motors). Presently, there exists commercially available controllers that can offer the same adjustability and use of a specific variety of input options but are designed for a particular model(s) of power wheelchair. The ability to fit a given controller for use on any power chair is not presently available. This R&D effort has resulted in precommercial models (user and clinical) that are now ready to undergo pilot evaluation managed by the Department of Veterans Affairs (VA) Rehabilitation R&D Service's, Technology Transfer Section. This paper discusses the preliminary aspects that were involved in bringing this emerging technology into the VA's transfer process.

BACKGROUND

The mission of the Department of Veterans Affairs (VA) Rehabilitation Research and Development (Rehab R&D) Service is to support an intramural program for improving the quality of life for veterans with disabilities. One of Rehab R&D's priority areas involves spinal cord injury (SCI) . Within this priority area, there is close collaboration with Physical Medicine and Rehabilitation (PM&R) and Prosthetic and Sensory Aids (PSAS) Services. The VA funds R&D that can result in products or techniques with potential to: promote greater functional independence in activities of daily living (ADL), and ameliorate treatment, management, and rehabilitation of veterans with disabling disorders. Successful outcomes are not only disseminated throughout the VA but also transferred into the national health care system where benefits can be derived for persons with similar disabilities.

One important aspect of functional independence is mobility. In terms of power wheelchair mobility, technological advances have led to innovative designs in the area of controllers. The vast array of control options presently available help to increase opportunities for persons with physical limitations to achieve independence within their environment. In maintaining its commitment to support advancement of technologies that have important relevance within the SCI priority area, the VA Rehab R&D has within its purview the Technology Transfer Section (TTS). The TTS assists in facilitating the validation, commercialization, and clinical application of developed products/techniques primarily funded by the VA Rehab R&D program. Non-VA funded developments are also reviewed, with collaboration from appropriate VA Central Office (VACO) Service Directors, to determine if the development meets an exigent need within a VA priority area that is not being met by commercially available products nor that similar developments are not being VA funded. If this criteria is satisfied, then the TTS will initiate a recommended plan to procure precommercial models for clinical evaluation and otherwise facilitate its technology transfer.

The Advanced Wheelchair Electronics Controller (AWEC) was developed at the Daniel Carney Rehabilitation Engineering Center (REC), and funded by the Cerebral Palsy Research Foundation of Kansas, Wichita, KS. The AWEC is a software-driven wheelchair controller that allows: adjustability of operating parameters; interchange of input control options; and retrofit for use on any power wheelchair (with two good motors). This non-VA funded development was reviewed, in collaboration with VACO Directors from SCI, PM&R and PSAS, resulting in a positive response to proceed with a three month pilot evaluation to fully determine the potential impact that the AWEC could have for both the clinician and end user for improving rehabilitation and independent mobility. The critical element of the AWEC is its claimed universal compatibility. There is presently no controller, commercially available, that can be retrofit for use on any existing power wheelchair, nor cross input controls that are not manufacture specific.

The developers at the REC felt that the specific target population for the AWEC is virtually any person who has a mobility impairment necessitating the use of a power wheelchair. They anticipate that there would be two specific markets. First, the user model, would benefit persons who may require a change of input control based upon a change in their functional status. This controller would allow interchange of control options without the added cost of purchasing a more expensive controller and/or model power wheelchair. For example, a person with a degenerative disability, such as multiple sclerosis, could have their control input changed over time without the purchase of new equipment. Commercially available controllers have the capability to program performance and function parameters but are designed for use with only specific wheelchair models. Secondly, the clinical model, would provide therapists, and others involved with prescribing wheelchairs, a dynamic method for conducting power wheelchair assessments to determine if the person would be a candidate for power mobility and the most appropriate control arrangement. The ability to retrofit the AWEC on existing power wheelchairs could potentially eliminate the need to purchase new power wheelchair, or more expensive add-on equipment, in order to use a particular control interface.

PRODUCT DESCRIPTION

The software-driven AWEC allows the clinician to readily change the control input option by simply turning a knob located on the electronics box. The AWEC can accommodate the following control methods:

Proportional control

- Two switch coded control
- Four switch control
- One switch coded control
- Three switch coded control
- One switch scanned control

The operating parameters are adjusted via potentiometers located internally on the user model and externally on the clinical model. These parameters include:

- Maximum forward speed;
- Maximum reverse speed (independent of maximum forward speed);
- Left and right turning speed (the amount of force applied to both wheels for a valid turn);
- Acceleration rate (the amount of time to move from zero to the maximum allowed speed);
- Braking rate;
- Chair reaction time (defines how fast the chair will respond to a command input: 1 - 10 sec);
- In-course correction speed (the sharpness of a turn allowed in course correction mode);
- Course correction enable/disable (turns on/off the in-course correction capability); and
- Course correction action (directs chair on how to respond if two switches are activated).

The electronic components for all listed functions are contained within one enclosure. This allows the user to move between input options previously listed, without purchasing additional electronic components (excluding input switches). In addition, the AWEC may be incorporated onto essentially any power wheelchair that has two good motors.

VA TECHNOLOGY TRANSFER PROCESS

Within the VA Rehab R&D the TTS facilitates the progression of proven developments into clinical use, product manufacture, and commercial availability. This is accomplished, with collaboration from appropriate VACO Directors, by manufacture of precommercial models, and management of objective, multi-center clinical research evaluation studies. These studies validate the safety, effectiveness, clinical application, and commercial readiness of the precommercial model. Successful outcomes are disseminated VA-wide and ultimately into the national health care system so benefits can be realized by veterans and non veterans with disabilities.

Initial testing performed by the developer on two working prototype (alpha) versions of the AWEC provided qualified data demonstrating potential clinical application of the AWEC. These encouraging results fueled the need to continue development toward a commercial product. Subsequently, a Request For Evaluation (RFE) was submitted to bring the AWEC into the VA Rehab R&D's technology transfer process.

The RFE is a screening process employed by TTS to identify developments that have reached a stage of accomplishment appropriate for acceptance as a technology transfer project. A RFE review of the AWEC, with collaboration from the following VACO Service Directors: PM&R, PSAS, and SCI, resulted in a recommendation to proceed with a pilot study. Results from the pilot would assist in assessing the level of need and possible impact the AWEC would have upon the overall rehabilitation and functional mobility for veterans with physical impairments.

The AWEC project received positive RFE review and approval from the Director, Rehab R&D to proceed with the evaluation phase. A procurement contract for the manufacture of ten precommercial models of the AWEC was awarded to the Daniel M. Carney, REC (Wichita, KS) which is committed to marketing the AWEC pending the outcome of the clinical evaluation. The primary marketing goal of the REC is to meet the needs of the physically disabled population in the most cost effective and reliable manner possible. It is their hope to market the AWEC as follows to meet this goal:

- Offer the product as an "add-on" component, remaining unspecified to manufactured brand of power wheelchair;
- Retain the flexibility of the product without the cost of additional hardware or software;
- Provide the capability of repairing the hardware "in the field."

With collaboration from the various VACO Directors, the following three VA evaluation sites have been selected to participate in the three month pilot: Memphis, TN; Tampa, FL; and San Antonio, TX. An evaluation protocol has been established to include methodology, subject selection, and data instruments.

DISCUSSION

This pilot study is being conducted to obtain further data on the technical merits of the AWEC and its application within the clinical environment for both the end user and clinician. It will also identify any modifications that may be required to improve its optimal use and enhance marketability. At such time, a determination will be made on whether the AWEC is ready for commercial production and marketing.

Saleem Sheredos, Rehab Engineer
Program Manager
VA Rehab R&D Service
Technology Transfer Section
103 South Gay Street
Baltimore, MD 21202
(410) 962-2133

PRODUCT COMMERCIALIZATION - NEW SILICONE ABILITY SWITCHES FOR THE DISABLED

Eric W.C. Tam and Eddie Y.M. Chiu
Rehabilitation Engineering Centre
The Hong Kong Polytechnic University
Hunghom, Kowloon, HONG KONG

ABSTRACT

Three types of ability switches, including press, touch and pinch, have been produced as a result of our first attempt to involve local industry in producing assistive devices for the disabled. These switches were designed with special emphasis on their functionality as well as on their cosmetic appearance. The use of silicone rubber has allowed for flexibility in the manufacturing process which helps to lower the cost, especially when the required production volume is small. This paper presents our experience in conducting this pilot project.

BACKGROUND

Persons with physical disabilities may require to control electrically operated assistive devices in their daily living. Examples include controlling a wheelchair, manipulating a robotic arm for self-feeding, accessing a computer or communication board, or even playing with a toy. All these control activities are achieved through the use of certain input devices, which are usually a form of ability switch. In Hong Kong direct financial provision for assistive devices is confined primarily to medically-related cases and there is a welfare allowance. As a result, ability switches are often home made and provided on a one off basis. Over the years, the Rehabilitation Engineering Centre has been designing and fabricating a variety of switches to meet the need of individual users, which were priced at the material costs. Although these switches have proven to be durable, the major drawback is in terms of their cosmetic appearance, which sometimes may imped the effectiveness of the rehabilitation and training program especially for the disabled children where perceptual stimulation is required.

In 1991, the Rehabilitation Engineering Centre initiated a project to develop and fabricate a range of ability switches through the local industry which was targeted to meet the demand from the majority of users in the local disabled community. Although this project has gained financial support from a charitable organization, the funding granted solely covered the basic production cost. A market survey was launched in early 1993 to identify the types of switches under demand. A design team consisting of a rehabilitation engineer and an industrial designer from the Rehabilitation Engineering Centre was established and worked closely with the engineering team from the manufacturer counterpart, to design and fabricate these switches within the budget.

OBJECTIVES

The aims of the project are to establish an industrial link for the commercialization of assistive devices, and to determine a few types of switch which will meet the demand of the majority of disabled people. These switches will be designed both in terms of functionality and cosmoses. Fabrication of these switches will be conducted by an experienced manufacturer, and the final products will be sold at an affordable price to the disabled community. The profit from the sale of these switches will then be set aside for future use in commercializing other assistive devices.

MARKET SURVEY

Adequate financial support and a proven market are essential for the commercialization of a product. In order to convince our manufacturer partner that there is a definite demand for ability switches by the disabled community and to identify the need for various types of ability switches by the community, particularly in special schools, a survey on the need, as perceived by the disabled was conducted. The survey was structured in two parts: Part one of the questionnaire is designed to solicit general information related to the respondent as well as the source, application and mounting requirements of ability switches in use; part two is an itemized list of ability switches which are frequently in demand. In the second part, two questions were asked including a triennium projection on the demand for various types of ability switches, and their expected sales price. The questionnaire was sent to every special school and therapy department in hospitals. The respondent was either the officer-in-charge, a therapist, a social worker or a teacher. The result of the survey revealed that the platform (pressure pad) switch, pinch (thumb) switch and touch switch were the four most common types of switches in demand. The expected price for these switches perceived by the users was below US$13. Currently, the supply of ability switches is mainly provided by local non-profit rehabilitation engineering services agencies. The application of these switches is primarily for computer access or playing games, and normally, these switches are for stand-alone use. The majority of the respondents were therapists who should well recognize the demand in the field.

DESIGN CONSIDERATIONS

According to the result of the survey, and in order to maximize the variety of switches that can be produced within the budget of this project, the platform (pad) switch, pinch switch and touch switch were selected for production. The size of each batch was confined to 50. Design specifications were based on our past experience in producing ability switches for the disabled. In terms of functionality, these switches should be durable and, particularly able to withstand uncontrollable forces exerted by users with spasm. A tactile feedback upon activation would also be desirable for the user. In the design of the touch switch, we anticipated that a specified activation force could be met. In terms of cosmetic appearance, these switches should be colourful and have an appealing look. In addition, these switches should be waterproof, easy to clean and safe for use.

Based on these specifications, we have considered to design a mechanical type device. However, it would be difficult and costly to produce a touch switch. Also, mechanical type of switches usually require more labour time in the assembly phase during production. Secondly, the membrane type technique for switch production has been considered. The major drawback is on its durability in use, especially under rough usages.

Silicone rubber based switches, which are commonly used as key pads in modern telephones and medical equipment, are ideal for this project. Silicone itself is non-toxic and can be easily produced in many different colors. The required toolings for production are comparatively cheap and by carefully designing the switch assembly, minimal components are required to form a water proof switch set. In addition, the activation force can be specified and designed into the mould. When compared to mechanical and membrane switches, silicone switches are usually more durable. Also, cleaning can be made easily by using a wet cloth which solves the hygienic problem of excess saliva as commonly seen in children with cerebral palsy.

DISCUSSION

The new silicone ability switches were made in order to provide a better solution to disabled people in need. The technique of using carbon coating on silicone rubber as the conducting medium prohibits the use of these switches under high current conditions. In practise, most of the applications of these switches are for on-off control of low current electronic devices. For direct power switching, a "black box" which consists of some electronic switching components is required if these switches are to be used. These switches have also been tested by the manufacturer for durability at a stroke rate of 120 times per minute for 1.5 million times with no reported failures. The price of these switches was set at an average of US$35 in order to fully recover the production cost. Although the price deviates largely from the users' expectation, when compared to the price of other commercially available switches on market which were sold at an average of US$75, these new silicone switches can definitely meet the local need. This project also demonstrated our first experience in collaborating with industry to produce small batches of assistive devices. It is our aim that through such collaborative work, manufacturers would become more willing to spare some of their production capacity to help the disabled community.

ACKNOWLEDGMENTS

This work is support by the Duty Free Shoppers Charitable Trust, the Royal Hong Kong Jockey Club (Charitable) Ltd. and the Hong Kong Polytechnic University. The authors gratefully acknowledge support from the Modern Medical Equipment Manufacturing Ltd.

Eric W.C. Tam
Project Engineer
Rehabilitation Engineering Centre
The Hong Kong Polytechnic University
Hunghom, Kowloon
HONG KONG
Tel: (852)-2766-7670
Fax: (852)-2362-4365
Email: RCERIC@HKPUCC.POLYU.EDU.HK

ROBUST ENVIRONMENTAL BIG BUTTON SWITCHES

Kathleen L. Kitto
Western Washington University
Engineering Technology
Bellingham, WA U.S.A.

ABSTRACT

The physical therapists at the Children's Neuromuscular program approached the faculty and students in the Engineering Technology Department at Western Washington University to design and produce robust environmental and toy switches to assist them in their efforts with children with motor function disabilities - especially children with cerebral palsy. The switches that were designed, produced and donated to the program by the faculty and students are tough, clear polycarbonate switches with separate AC switch boxes that plug into standard wall outlets and replace unsatisfactory, modified, brittle polystyrene audio cassette box switches. This paper describes these robust polycarbonate switches and the AC environmental switch in detail, as well as the development effort. Ultimately, 100 switches and 50 AC control boxes were donated to the program.

BACKGROUND

The physical therapists at the Children's Neuromuscular program approached the faculty and students in the Engineering Technology Department at Western Washington University to design and produce robust environmental and toy switches to assist them in their efforts with children with motor function disabilities - especially children with cerebral palsy. The therapists were using modified polystyrene audio cassette boxes in their programs. Unfortunately, these polystyrene switches are unsatisfactory because they are brittle and break often during use. The plastic shatters and the resulting pieces are often sharp. Clearly, they needed a better switch.

The students in the Robotics and Automation class at Western Washington University design and produce products for differently abled individuals. Parts for the devices are funded by a small National Science Foundation grant. The students designed and initially produced 50 switches to turn on and off battery operated devices used in therapy. The therapists quickly realized these robust, big button switches would be useful for environmental controls as well. In response, the faculty and students created an AC environmental switch box. One side of the AC switch box plugs into a standard AC wall outlet. The other side of the control box plugs into the big button switch. Another 50 switches and 50 environmental control boxes were produced and donated to the Children's Programs in Bellingham, Washington.

The therapists have successfully been using these switches for approximately one year. Since the switches are made from tough polycarbonate, they are robust and they do not break in service. Because of the switch design, the switches can also be operated by individuals who can apply only a small amount of force, either with a hand or a foot. The all purpose switches are simple to make and can be used by individuals with a large variety of motor function problems.

SWITCH DEVELOPMENT

After talking with the physical therapists at the Children's Neuromuscular program, the class/faculty identified design parameters. The switches had to be large and durable, so they could be pushed easily and hit hard by children with limited or uncontrollable motor skills. They also had to be isolated from the AC power for safety and be flexible enough for a variety of uses.

The big button switch is made from six parts:

1. a polycarbonate cover/base,
2. a circuit board,
3. two momentary switches with a 7.5 volt female jack,
4. a picture cardholder,
5. VHB (Very High Bond) tape and
6. rubber feet.

The polycarbonate stock material came in a sheet 9/16 inch thick and was 12 feet by 8 feet wide. The polycarbonate was cut into sections with a carbide blade in a table saw. The final size of the flat switch before bending is 4 inches by 10 inches.

Sharp edges were buffed smooth and edges rounded with a circular sander.

The switch printed circuit board is 3/4 inch wide by 3.75 inches long. Two momentary switches at each end of the printed circuit board are soldered to the board. A female jack is soldered to the printed circuit board between the two switches.

The circuit board is bonded to the polycarbonate with a small strip of VHB tape (Very High Bond by 3M) on the back of the printed circuit board. VHB tape produces a very strong bond suitable for the rough service conditions of the switch.

A clear, baseball cardholder is placed inside the switch so that the therapist can put a large picture of the device to be operated inside the switch. The therapists specifically requested this feature. The cardholder is also bonded to the polycarbonate by four circular pieces of VHB tape. Four rubber feet are then attached to the bottom of the finished product. The rubber feet prevent the button from sliding on smooth or slick surfaces.

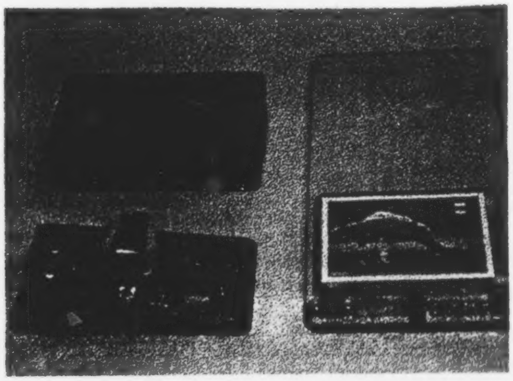


Figure 1. Materials for Big Button Switch and Environmental Controls

AC SWITCH DESIGN

A class/faculty/therapists discussion determined the operating parameters of the AC environmental control circuit. A preliminary design of the circuitry was sketched and simulated on PSpice and Micro-Cap software. Modifications were made to the circuit design to optimize performance. Cost estimates and component availability were assessed, and more modifications were made. Components were selected based on function, availability, and cost. UL requirements were kept in mind through the entire design process. A working circuit was then assembled on a prototyping board and tested. Again, more modifications were made in order to optimize performance. Discussion with the group on how the final product should be enclosed and assembled dictated the location of some components. These locations were finalized, and the dimensions were forwarded to the group member in charge of machining the case. The assembly method decided upon was to have all penetrations through the case insertable from one side. This layout simplified the assembly procedure, since the objective was to assemble the product in a robotic workcell. The layout also simplified machining of the case. The actual circuit board layout was designed around the components that penetrated the case. VHB tape was determined to be the simplest bonding solution for holding components to the circuit board, and also securing the circuit board inside the case. The circuit schematic is shown in Figure 2. The Parts Lists for these assemblies in given in Tables A and B.

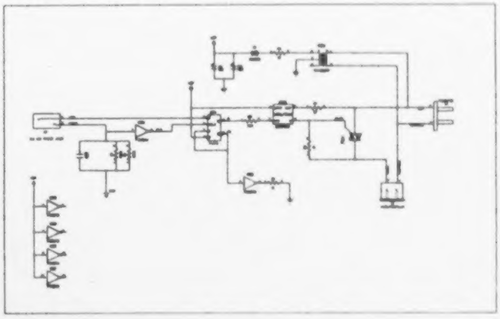


Figure 2. Schematic for AC Environmental Control Box

TABLE A. Big Button Switch Parts List

Desctiption	Part Number	Vendor
Keyboard switch (2)		Vetco
Circuit board		custom WWU
3.5mm Jack	1613505	Mouser
3.5mm ph. plug (2)	171-3302	Mouser
2 cond. 20 AWG cable lengths of 5, 10, 15, 20 feet		Vetco
polycarbonate VHB Tape	3M	

TABLE B. AC Switch Blue Box Parts List

Description	Part Number	Vendor
Blue Box		Radio Shack
12.6v Trans.	41PG006	Mouser
Rectifier Diode	1N4004	Mouser
100uF Cap.	140-XLR16V100	Mouser
AC jack	15AC037	Mouser
3.5mm ph. jack	1613505	Mouser
Optoisolator	MOC3041	BG Micro
D-Flip Flop	74LS74	BG Micro
Schmitt trig. inv.	74HC14	BG Micro
Triac	MAC223	Newark
1uF Cap.		Active
200 ohm Resistior		Active
1 Meg Resistor		Active
1k ohm Resistor	(2)	Active
27 ohm Resistor		Active
47 ohm Resistor		Active

The switches were assembled in an agile manufacturing workcell at Western Washington University. Each year the students design the fixtures and tooling to make the product under consideration automatically in the workcell. The series of operations and the final products are described in Figures 3 through 5.

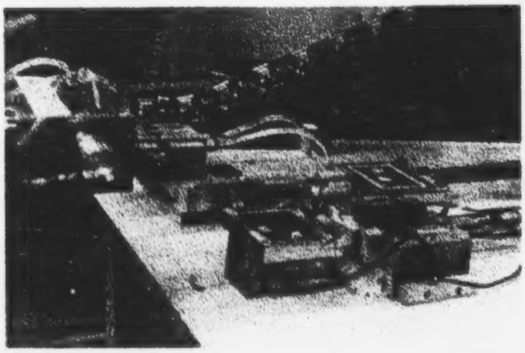


Figure 3. Heating and Bending the Polycarbonate during Robotic Assembly

CONCLUSIONS

Robust environmental switches made from durable, tough polycarbonate have successfully replaced brittle polystyrene switches in a rehabilitation program from children with cerebral palsy. The switches serve a wide range of individuals with an equally wide range of disabilities.

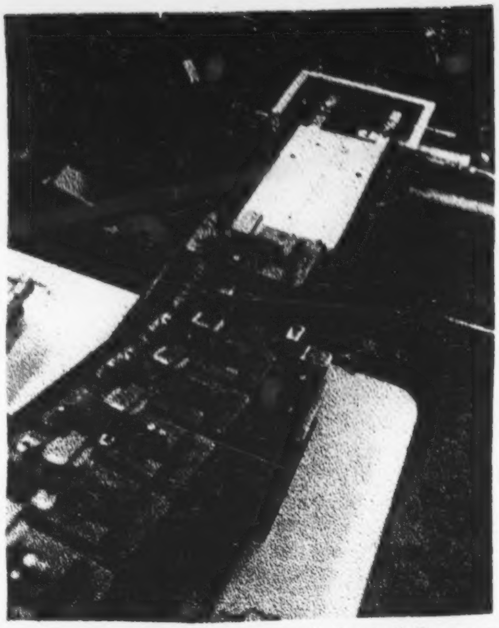


Figure 4. AC Environmental Control Boxes are Assembled in the Workcell.

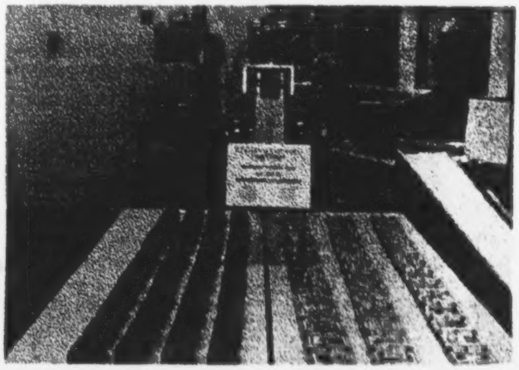


Figure 5. The Completed Switches and Environmental Control Box

ACKNOWLEDGMENTS

Funding for this project was supported by the National Science Foundation (NSF) "Undergraduate Design Projects to Aid the Disabled" (grant number BCS-9210889). Thank you to the Children's Neuromuscular Program for their input and cooperation.

Kathleen L. Kitto
Western Washington University
Engineering Technology
Bellingham, WA U.S.A.
(360) 650-3506 office
(360) 650-4847 fax
kitto@henson.cc.wwu.edu

BEST COPY AVAILABLE

CAD/CAM FOR PROSTHETICS: SUCCESSFUL TECHNOLOGY TRANSFER

Aaron W. Joseph MS, David A. Boone CP, David E. Mathews CP, Douglas G. Smith MD
Prosthetics Research Study
Seattle, WA USA

ABSTRACT

Our experience in developing a CAD/CAM system for designing prostheses and orthoses illustrates many of the problems in transferring technology from a research laboratory into regular clinical use. Some key factors in the successful technology transfer were: 1) the close and continuous collaboration between clinicians and engineers during development; 2) a relatively long period of clinical testing of prototypes with subsequent improvements in design; and 3) involvement of the research staff throughout the technology transfer process, including commercialization, training, and technical support. Commercialization of a new technology poses a number of potential problems. For example, research prototypes may be uneconomical to manufacture, and a lengthy re-design may result. Companies producing a conventional device may resist abandoning their investment to begin manufacturing a technologically superior device. Further, technology transfer can be hampered by the resistance of users to switch from a traditional system to the new technology.

BACKGROUND

The design and fabrication of a lower or upper limb prosthesis requires extensive clinical expertise in evaluating the biomechanics of a patient's residual limb as well as technical expertise in sculpting anatomically compatible shapes. The socket which forms the interface between the artificial limb and the patient's body must be custom-fitted for each patient and is thus the most difficult part to make. The socket shape cannot be simply an exact replica of the shape of the residual limb. The prosthetist must decide how the forces should be transmitted between the prosthesis and the patient's body and alter the shape to apply more force where the tissue can withstand it and less force where the tissue is too delicate or sensitive and may break down or cause pain. Changes of a few millimeters in the shape of a socket can mean the difference between a leg which allows a patient to play rigorous sports and a leg which is too painful to walk more than a short distance.

The conventional method for making a prosthetic socket involves casting the patient's stump, making a positive plaster mold from the cast, hand sculpting the plaster mold into the desired socket shape, and then fabricating the actual socket over this mold by laminating fiberglass or vacuum forming thermoplastic. This process can take many hours to complete. Using modern Computer Aided Design and Computer Aided Manufacturing (CAD/CAM) technology, the design and fabrication of a socket can be done in as little as one hour. Because much of this time is spent waiting while the automatic fabrication equipment runs, a prosthetist can spend more time with patients.

The sockets of lower limb prostheses may need numerous modifications, especially during the first six months following amputation. Changes in limb musculature, changes in body weight, or decreased swelling following amputation all require major socket modifications. Minor changes can be made by sanding away material or adding padding to the inside of the socket but major changes require repeating the entire design and fabrication process. In the case of modifying an existing socket, a CAD/CAM system for prosthetics offers the same advantage of a word processor over a conventional typewriter—it is no longer necessary to repeat all the work each time a change is made (2,6).

Researchers have discussed the advantages of CAD/CAM systems for prosthetics for many years (4,6,7). The first complete working prototype CAD/CAM system for prosthetics was built and demonstrated in 1983 by the Medical Engineering Resource Unit of the University of British Columbia and the Bioengineering Centre of University College London in England (3). During the following years extensive clinical testing of this system as well as other versions was conducted at a number of research centers in the USA, Canada, England, and Sweden. In 1985 the US Department of Veteran Affairs Rehabilitation Research and Development Service (DVA RR&D) began a coordinated program nationwide to develop and evaluate this emerging technology (5). The term AFMA, for the Automated Fabrication of Mobility Aids, was chosen to encompass CAD/CAM for prosthetics as well as related technology for making foot orthoses, custom wheelchair cushions, etc. AFMA technology has progressed considerably over the last decade and the hardware and software are now sold by companies in the USA and in other countries.

A modern AFMA system for prosthetics (Figure 1) consists of three basic parts: 1) a digitizing device to measure the shape of the residual limb and transfer the data to a computer, 2) software to design a socket based on the limb shape, and 3) a computer controlled carver to replicate the computer shape in a plaster mold. A fourth machine, an automatic thermoforming oven to speed fabrication, is usually included. This system not only improves the productivity of a prosthetist/orthotist, but also improves the science of socket design by making the process quantifiable and repeatable. An AFMA system very rapidly produces a good fitting socket and provides sophisticated software tools to allow a prosthetist to further fine tune the socket design for each patient (2). A prosthetist can now easily duplicate a socket if a patient needs a second limb or evenly decrease the size of the socket while preserving its shape to accommodate a patient whose limb has shrunk. Further, by encoding the shape as a computer file, a socket design can be easily sent from one AFMA clinic to another for centralized fabrication, for research purposes, or for following a patient moving to a new location.

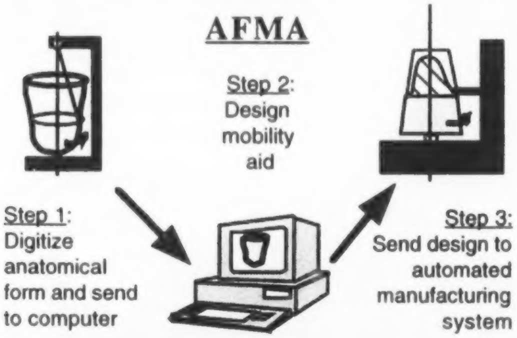

AFMA
Step 2: Design mobility aid
Step 1: Digitize anatomical form and send to computer
Step 3: Send design to automated manufacturing system

Figure 1

Transferring this technology from research prototypes into commercial systems in clinics involved considerable challenges. AFMA technology is inherently complicated, requiring the integration of different machines from competing manufacturers and sophisticated graphics software. This complexity created difficulties in commercialization, training, and technical support. The biggest challenge we faced, however, came from the resistance of the end-users to switch from conventional techniques to AFMA. Despite the seemingly obvious advantages of this new technology, many prosthetists/orthotists considered it unnecessary and felt that the system emphasized productivity over quality. Based on the design of early prototypes, they feared their expertise would be replaced by a push-button system (7).

OBJECTIVE

Our initial goal was to decide whether the AFMA technology would be a viable approach for clinical use and if so, to identify necessary characteristics of a successful AFMA system for subsequent commercialization. Our final goal was to see that this new technology was eventually incorporated into regular use in VA hospitals to reduce costs and improve care of amputees.

APPROACH

We began participating in the AFMA program as one of three VA research centers evaluating the CAD/CAM prototypes through extensive clinical testing (1,5). We later began developing new AFMA hardware and software and promoted its use and commercialization. More recently, we designed and implemented an AFMA training program for practitioners from VA hospitals nationwide.

Our approach to research and development, as well as technology transfer, depends on the close collaboration between engineers and clinicians and extensive prototype testing with patients. During the testing and refinement of AFMA prototypes, prosthetists and physicians on our staff gave critical feedback on the practical aspects of using the system on a regular basis with their patients. Extensive clinical testing began as early as possible so that it could go beyond just correcting hardware and software bugs to influencing profound changes in the entire system; changes that not only added more features, but greatly increased the system's reliability.

We identified the early prototype software as a major problem in clinical implementation and began development of entirely new AFMA software (2). The new software, developed principally by a software engineer and a prosthetist, was designed to mimic as much as possible the traditional techniques a prosthetist uses to design a socket in plaster. In this way it builds on the user's clinical experience instead of requiring the user to learn a completely new approach. The software strikes a balance between the speed of a completely automated system and the quality of a hand-crafted design by automatically designing a "rough fit" socket and then providing sophisticated tools to allow a prosthetist to further fine tune the socket design for the individual patient. With this approach an AFMA system minimizes the technical work of socket fabrication while still allowing the prosthetist complete freedom in socket design.

In addition to developing and evaluating AFMA technology, we have also been actively promoting its acceptance by clinicians. Early in the technology transfer process, we participated in extensive clinical trials to establish the effectiveness of the new technology. We also helped organize AFMA workshops to present the new technology to other researchers and clinicians and discuss improvements with them (5). Later we set up AFMA systems at four pilot sites in VA hospitals. These pilot sites not only demonstrated the advantages of AFMA technology to VA personnel, they also provided us with valuable feedback on problems in training and technical support.

In 1994 we facilitated large-scale implementation of AFMA technology in VA hospitals nationwide. Our role in the program consisted of three parts: 1) teaching a 5-day formal training course in AFMA for prosthetics, 2) visiting each VA hospital for 3-5 days for on-site training and technical support , and 3) providing technical support by telephone. We designed the 5-day training course to concentrate on hands-on learning, emphasizing the practical aspects of using the new system. All the trainees worked with amputee patients during the course. Because many of the trainees had never used a computer before, the course begins with a full day of intensive practice in general computer skills. This helps to quickly overcome any anxiety about using a computer and allows the trainees to concentrate on prosthetics and the AFMA system for the rest of the course.

Throughout the development and technology transfer process, we strongly encouraged the establishment of open standards for AFMA technology to allow practitioners to combine components from different manufacturers. Open standards make it easier for new companies to enter the field and for rapid technological progress through commercial competition. While promoting the AFMA technology, we have always aimed to promote the overall concept of AFMA and important features of the system without promoting any one particular product or manufacturer.

RESULTS

Modern AFMA technology provides a cost-effective way to enhance patient care. AFMA systems are now in use at over 30 VA hospitals and at over one hundred sites around the world. Both private clinics and government hospitals have adopted this new approach in prosthetics and orthotics. Research and development continues for improving existing AFMA hardware and software and expanding AFMA technology into related areas such as foot orthoses and custom wheelchair seating. For-profit companies, in addition to government-funded laboratories, are now conducting R&D programs in AFMA.

DISCUSSION

From our experience in helping transfer this new technology from the laboratory to clinical use, we can identify certain key factors in its successful implementation. Close collaboration between engineers and clinicians steered development toward a system tailored to clinical needs. The prototypes were refined and validated during years of testing with patients. The development staff were involved at all stages of technology transfer—commercialization, training, and technical support. This participation provided critical information for improving the current system and for incorporation in future R&D projects. Persistence in promoting the AFMA technology through clinical trials, workshops, and pilot sites helped overcome resistance of companies to invest in the new technology and for practitioners to adopt this new approach in their everyday work.

The training program and technical support proved instrumental in the successful incorporation of AFMA into VA hospitals. We refined the training program during our work with the pilot sites in order to better tailor it to VA practitioners. Intensive technical support, both on-site and by telephone, was crucial in helping new sites get started. Those trainees have already used their AFMA systems to provide prostheses for hundreds of VA amputees.

Commercialization of a new technology depends on finding a company or companies willing to take the financial risk of manufacturing a new product. Companies already selling products in a particular market may not want to adopt a new technology before getting a return on their investment in their existing products. Conversely, companies outside of that market may consider it to risky to enter a new field.

From our experience we found that development of an initial prototype is just the first step in a long process until the new technology is both commercially available and in regular use. Researchers who want to see a new technology they have developed adopted for everyday use should be prepared to involve themselves both in the commercialization process and in working closely with the end-users of the technology.

REFERENCES

1. Boone D, Burgess E. Automated fabrication of mobility aids: clinical demonstration of the UCL computer aided socket design system. J Prosthet Orthot 1989:1(3):187-90.
2. Boone D, Harlan J, Burgess E. Automated fabrication of mobility aids: Review of the AFMA process and VA/Seattle ShapeMaker software design. J Rehabil Res Dev 1994:31(1):42-49.
3. Dewar M, Jarman P, Reynolds D, Jones K. Clinical trial of the UCL computer aided socket design system. Bioengineering Centre Report 1986, University College London, 1986:13-16.
4. Foort J. The Knud Jansen Lecture: Innovation in prosthetics and orthotics. Pros Orthot Int 1986:10:61-71.
5. Houston V, Burgess E, Childress D et al. National Program for the automated fabrication of mobility aids (AFMA): below-knee CASD/CAD testing and evaluation program results. J Rehabil Res Dev 1992:29(4):78-124.
6. Klasson B. Computer aided design, computer aided manufacture and other computer aids in prosthetics and orthotics. Prosthet Orthot Int 1985:9:3-11.
7. Michael J. Reflections on CAD/CAM in prosthetics and orthotics. J Prosthet Orthot 1989:1(3):116-121.

ACKNOWLEDGMENTS

This work was supported by the US Department of Veterans Affairs Rehabilitation Research and Development and Prosthetics and Sensory Aids Services.

Aaron Joseph
Research Engineer
Prosthetics Research Study
720 Broadway
Seattle, WA 98122 USA
(206) 328-3116 FAX: 325-3607

238

PRODUCT DEVELOPMENT THROUGH REGIONAL INTERNATIONAL CO-OPERATION, A NORDIC APPROACH

Ilkka Saarnio
NUH - Nordic Development Centre for Rehabilitation Technology
Tampere, Finland

ABSTRACT

A Nordic co-operation concept for the development of assistive technology is based on funding of development projects, supporting and funding of project preparation, and networking and information. Within 4 years, 38 project have been funded, most of which result in products onto the rehabilitation technology market. The concept has also created a platform for the Nordic RT actors to prepare joint development projects. The work will be linked to the research and development programmes of the European Union.

BACKGROUND

The close co-operation between the Nordic countries, i.e. Denmark, Finland, Iceland, Norway and Sweden has its origin in the common history and culture, tradition of co-operation and the need for rationalisation of efforts. Another general motive is the small size of the countries, the total population of the five countries being about 23 millions. Furthermore, regarding the rehabilitation and technical aid services, the countries have similar social welfare systems and technical aid provision policies and structures.

Four Nordic countries (Denmark, Finland, Norway and Sweden) also have a long tradition of co-operation within the standardisation and testing of technical aids: since 1978. This co-operation is based on common requirements and the sharing of labour: one country has the expertise and facilities to test the certain group of products marketed in all four countries according to the jointly agreed requirements and methods.

The companies developing and producing assistive devices are relatively small, the average annual turnover is about 1.5 million USD (1). The number of manufactures can be estimated to be in the order of 250 (2). The estimate of the Nordic assistive technology market is 900-1 000 million USD.

In order to utilise the Nordic co-operation also in the area of product development the Nordic Committee on Disability has taken the initiative in establishing the Nordic Development Centre for Rehabilitation Technology, NUH.

OBJECTIVE

The idea underlying the work of NUH is that it could promote the joint Nordic development of high technology based technical aids for people with disabilities, promote co-operation and distribution of labour, and encourage the sharing of experiences and research results.

APPROACH

The main areas of work of NUH are 1) funding of product development projects, 2) supporting and funding project preparation and 3) information and networking. NUH initiates Nordic development projects, creates and maintains contacts between the organisations within the sector, provides financial support for development work and assists in finding alternative forms of funding. The centre provides assistance in setting up preparatory project meetings, seminars and workshops and thus creates the companies, research institutions, users and other potential project partners a chance to make contacts, survey the needs, interests and resources, and prepare the project plans.

NORDTILL is one of the tools for the networking activities. It is a catalogue of the enterprises which develop or produce new technology based technical aids. The catalogue describes the features and goals of the operation of the companies, lists the products and gives the contact information.

The basic criterion in funding of the development projects is an industrial or commercial participation, or an exploitation plan already at the early stages of the projects.

RESULTS

Within 4 years, 1991-94, NUH has funded 38 projects and some 30 preparatory activities, i.e. workshops, seminars, work meetings and preliminary surveys. The work areas and products have ranged from devices and software for people with cognitive disabilities, design of programming tools, localisation of products, systems for training and decision support to information: design guidelines, software catalogues and guidebooks and surveys on market, requirements or new technologies.

70 % of the projects have been product development or localisation. From 1991 to 1994, 75 % of these projects have resulted in or are likely to result in new products on the market. This is due to the requirement of the commercial or industrial participation in the projects.

DISCUSSION

The results and the experiences of the described Nordic concept are mainly positive. One of the restrictions has been the relatively narrow economic framework: large development projects can only be partially funded. In these cases, the emphasis has been on supporting the start and early phases of a project which then has proved the viability of the idea and the product, and so facilitated funding from other agencies. In some cases, these funding agencies have regarded the NUH funding as a prerequisite for complementary funding.

The main co-operation concept in Europe in the area of research and development of rehabilitation technology is the TIDE (Technology Initiative for Disabled and Elderly People) programme of the European Union. The NUH concept is considered a complementary mechanism to TIDE for the Nordic actors. It has the flexibility to adapt to the needs and problems of the small enterprises.

The future work of NUH is closely connected to the European development and goals. As three of the Nordic countries have become members of the European Union the direction and the emphasis of the Nordic development co-operation is to be reassessed. The main questions are how the co-operation can be adapted to the European goals and procedures, how these experiences can be utilised in the development of European programmes and how the work can be integrated in a natural way into the framework of the European Union.

ACKNOWLEDGEMENTS

The work of NUH is funded by the Nordic Council of Ministers, a co-operation body of Denmark, Finland, Iceland, Norway and Sweden. NUH is a daughter organisation under the Nordic Committee on Disability.

REFERENCES

(1) NORDTILL 94, Catalogue of the Nordic developers and producers of new technology based technical aids, NUH, Tampere, 1994 (in Swedish)

(2) Coherence between and among Rehabilitation Technology Industrial Sector, HEART Project Report, Commission of the European Communities, 1994

Ilkka Saarnio
Executive Director
Nordic Development Centre for Rehabilitation Technology
P.O. Box 316
FIN-33101 Tampere
Finland
Tel +358 31 316 3330
Fax +358 31 316 3365
email saarnio@kau.vtt.fi

A FORUM FOR IMPROVING ASSISTIVE TECHNOLOGY PRODUCT DEVELOPMENT

EDWARD M. SPECHT
DEPARTMENT OF REHABILITATION MEDICINE
MT. SINAI MEDICAL CENTER
NEW YORK, NEW YORK

Abstract

Assistive technology service providers often encounter opportunities for new devices and products which have commercial potential but have limited avenues to forward these ideas to manufacturers who are likely to respond. Manufacturers of assistive technology devices have limited sources for new product ideas and market feedback on products which they intend to develop. This paper proposes the creation of a forum for improving communication between manufacturers and service providers concerning potential new assistive technology products. Three such potential devices are described, one of which has already been developed into a product as a result of input from service providers.

Introduction/Background

Many assistive technology devices are developed each year. Fabricated and modified devices created by clinicians are developed to meet individual needs of specific clients. Commercial products are created to generate sales and to meet a more general need. Ocassionally clinically developed products are successfully transferred to commercial markets. More often manufacturers seek input from clinicians regarding product ideas and feasibility for new products. This consultation process is usually informal and often depends on second or third hand input from representatives who may not effectively communicate technical issues to product development staff.

Manufacturers products have the advantage of an established distribution system, a reliable point of contact for information about features, availability, and repair or replacement in case of product failure, and consistent operation and documentation. Products created in the lab or the clinic have the advantage of being more precisely designed for the needs of the individual client for whom they are created and often fill a need which is not recognized by the manufacturing community. In many cases this need is not unique to the client being served but represents a broader need which exists in the disabled community. One objective of technology transfer has been to combine the benefits of these two areas with a resulting product which can be successful in the market and at meeting the needs of the community. By facilitating communication between clinicians and product developers a similar objective can be met.

Problem/Objectives

The assistive technology clinician is often confronted with the dilemma of a client who requires a device which current technology makes feasible but which is not currently available commercially. It is tempting to attempt to fabricate the device to meet the clients needs but easy to underestimate the resources required to accomplish this task. Problems which can arise include incorrect assumptions about devices to be modified, materials failure during assembly, testing or mounting, unanticipated safety or liability issues, and changes in design or discontinuation of products to be used which can result in incompatibilities or increased cost. Any combination of these can cause delays in implementation and impact a clients vocational or educational status. Even when fabrication is successful the ability to maintain and repair these "orphan" devices can tax the resources of the most well established service provider and leave the client in the lurch in spite of best intentions.

Identifying fabricators who can produce custom devices or manufacturers who are willing to develop commercial products based on recommendations are two ways to address this problem, but each of these has its limitations. Skilled custom fabricators are not always available and can be difficult to locate. It also takes time to identify appropriate manufacturing contacts and convince them that your ideas have merit. Clinicians and device users who do not have consistent contact with manufacturers seldom have an opportunity to convey ideas for new products or product improvements.

The converse of this problem is that manufacturers are often hampered in their ability to obtain valuable market information about potential product acceptance and application. Gathering this type of information is very costly and usually beyond the resources of small manufacturers who seem to rely mostly on service providers in their own geographic region, which may not be representative of the larger market. Larger manufacturers are often insulated

BEST COPY AVAILABLE

from consumers and clinicians by layers of sales reps and dealers, who can prove useful, but often filter out significant details. The University of Buffalo RERC has recently instituted a program to address this problem but more can be done.

A forum is needed to enable clinicians to more easily approach manufacturers interested in product development with suggestions about real world needs of clients and practical solutions. Such a forum would enable any clinician to reach interested manufacturers with realistic product suggestions reinforced with the comments and suggestions of other experienced professionals. It would also serve as a clearinghouse for valuable but little known devices which meet unique needs. The exhibit hall at RESNA's annual convention and other similar forums begin to address this need, but more is required. By facilitating communication between clinicians and manufacturers it is possible to develop and deliver more products which meet a need and which are viable in the marketplace.

Method

There are several criteria for establishing a forum to improve communication between manufacturers and assistive technology clinicians. Time required to participate must be minimized to accomodate clinicians already over filled schedules. Time required to manage the system must be minimized due to limited resources available to implement the project. Opportunities for participation and communication should be maximized to create the best environment for product development.

This author proposes to establish a clearinghouse for clinically originated product ideas. The objective is to identify and develop ideas for assistive devices and forward these ideas to manufacturers who are likely to develop the ideas into actual products. This is to be implemented primarily through faxed communications. Faxes have the advantage of being accessible to more programs than E-mail while better limiting time necessary for communication than phone and requiring fewer resources to implement than a published/mailed newsletter. Based on available resources it may also be possible to implement a Fax Back system which would further reduce time requirements for maintaining the clearinghouse and improve accessibility.

Any inquiry about the clearinghouse would be instructed to supply a fax number and contact name. A packet of forms would then be forwarded to the inquirer, including a short program description, a Submitter Description Form used to provide some background on those who submit product ideas, a Device Recommendation Form on which product recommendations would be submitted, a Recommendation Support Critique Form used to comment on previously submitted recommendations, an Product Developers Form used to identify interests and resources available to manufacturers, a Manufacturers Response Form used to get manufacturer comments on proposed devices, and a Manufacturer Submission Form which would enable manufacturers to submit product ideas for comment by assistive technology service providers.

A distribution list is created based on inquiries, submissions, and available resources. Device recomendations are organized with their associated comments and current status of development and faxed to the distribution list periodically for further comment. A Manufacturers Referral Form which summarizes device descriptions and associated comments is forwarded to appropriate manufacturers periodically with a request for return of a Response Form.

Discussion

Suggestions for new products may include products which add functionality to currently available products, which allow two or more currently available products to work together, or products which take advantage of mass market technology and pricing and which can be readily adapted to assistive technology applications. Proposed here are several devices which our assistive technology clinic has identified as useful to multiple clients and which were not, to our knowledge, currently available in the marketplace. One of these devices has already been developed and adopted by a manufacturer as a product.

The Ringmouse is a substitute computer mouse which uses an ultrasonic transmitter and a monitor frame with embedded receivers to interpret hand movements as mouse movements. It is small and light weight enough to be mounted on a head strap as a head pointing device. To be effective for persons with movement disabilities the switches which control the mouse "click" would need to be made accessible to alternate switch inputs. Tweaking of the mouse acceleration table for head pointing would be helpful. The retail price of the unadapted Ringmouse is $100, which allows for pricing of a modified version at much less than current head pointing devices in the $1,200 to $2,500 range.

PRODUCT DEVELOPMENT FORUM

In recent years many persons with movement disabilities have obtained voice recognition computer systems to assist with written communication for home, school, or work. The TEAMS Lab at Mt. Sinai has encountered several clients who require concurrent access to the computer and to a telephone. A microphone control which would allow the client to use the same microphone to operate the phone and the computer concurrently would benefit many of these users and allow them to be, and to appear, more independent in phone conversations with business associates. Such a device should allow the person to speak to the computer without being heard on the phone line while still being able to listen to information from someone on the phone. Such a device which could be marketed for less than $300 would be a valuable addition to most of the voice recognition computer systems being provided.

Single function devices operated by a single switch can provide access to many activities for persons with severe movement limitations. Call signals, door openers, communication devices and telephones are a few examples. But when the client is only able to operate one or two switches, selection of the devices to be operated can be frustrating. Switch controlled ECU systems overcome this limitation but at a cost which may be out of reach. A simple circuit can be designed to channel a switch input to multiple outputs which can then be directed to multiple devices. At the recommendation of several clinicians one manufacturer has developed a product to do just that. The device is expected to be available shortly for about $100.

EDWARD M. SPECHT
ASSOCIATE DIRECTOR, TEAMS LAB
MT. SINAI MEDICAL CENTER
NEW YORK, NEW YORK 10029

(212) 241-3966
FAX (2120348-5901

IMPROVING TECHNOLOGY TRANSFER: THREE PRIORITY AREAS

Joseph P. Lane
RERC on Technology Evaluation and Transfer
Center for Assistive Technology, University at Buffalo
Buffalo, NY, U.S.A.

ABSTRACT

Technology transfer activities, like the broader field of assistive technology, are inefficient due to fragmented conditions and ineffective due to disjointed efforts. Technology transfer can become more efficient and effective by establishing a mechanism for identifying and sharing information about relevant constituencies and resources. The paper presents three priority areas being addressed by RESNA members, and describes their relevance to technology transfer.

BACKGROUND

The term technology transfer means the successful implementation of something previously developed within a new application. Technology transfer is sought because the knowledge produced by some previous investment of time and resources, yields additional value without repeating the investment. Thus, technology transfer is perceived as a device for leveraging existing resources in new ways. As such, the technology transfer process must demonstrate a net savings to the user.

At present, technology transfer is perceived to be difficult to accomplish within the field of assistive technology. The field itself is fragmented, the applications of technology are diverse, and the participants represent multiple, interests. There are few indications that technology transfer is a feasible process to pursue.

OBJECTIVE

RESNA, as a professional society, provides an opportunity to link some of these diverse stakeholders. The Technology Transfer Special Interest Group provides a forum for increasing the opportunities to accomplish technology transfer. More importantly, to improve the perceived feasibility and thereby encourage attempts at technology transfer.

APPROACH

The 1994 RESNA conference included a series of special sessions focused on improving the technology transfer process. The sessions involved the four primary stakeholders in technology transfer: consumers, researchers, businesses and government agencies. They identified a dozen areas requiring improvement. Of those, participants identified three general priorities for immediate action. They then determined how to address those priorities with the resources and knowledge currently available.

RESULTS

The main attributes of these three priority areas and examples of current activities are presented below.

Priority #1: Information Networking. To encourage technology transfer we need to improve information networking between stakeholders in the commercialization of assistive technology. Sharing information on past, current and planned activities is the unanimous top priority for all stakeholders in technology transfer. Resources are insufficient to continue re-inventing the wheel. The opportunity cost of repeating past development efforts is a luxury the field cannot afford. RESNA members are addressing this priority by identifying and linking communication methods presented by electronic networks, paper and conference sessions, organizations and government programs.

Electronic Networks - Identify the various electronic communication networks available for use (e.g., ENABLE/RIS, Word Wide Web, and Gophers). Identify the network users who are stakeholders in technology transfer. Determine a process to reach people across multiple networks while minimizing their need to access multiple networks.

Paper/Conference Networks - Identify the printed materials that reach stakeholders (journals, periodicals, newsletters, announcements). Identify the conferences they attend (vendor, research, professional, consumer). Determine how to identify and share information across multiple paper/conference networks.

Organization Networks - Identify viable models of collaboration for emulation. Identify hub and spoke networks within each stakeholder domain (FLC/NTTC, Tech Act Programs/RESNA/Project). Identify means to exchange information across spokes and between hubs.

Government/Policy Networks - Identify government programs in North America and elsewhere that support information and technology exchange (VAR&D, NIDRR, TIDE). Determine how government policies enhance information exchange (SBIR/STTR Programs, TRP) (1).

Priority #2 Market & Marketing Information

The four stakeholder groups each have information with value for the other groups. Technology transfer and commercialization efforts suffer if stakeholders miss an opportunity for broad information exchange. Re-inventing the wheel is bad, but re-inventing the square wheel is worse. Work in this priority area addresses generating and sharing market and marketing information on existing and on new assistive technology devices.

The primary tasks underway are to identify the existing resources for obtaining market and marketing information, exploring options for collecting the information not currently available, and determining the most effective means for making this information available and for demonstrating its value to the stakeholders.

Priority #3 Support Marketplace Transactions

To ensure that technology transfer efforts provide value to the stakeholders, the stakeholders must identify themselves and their technology needs. They must show themselves if they wish to be found by others. The field needs a communications and informational link between the demand pull and the supply push forces of the marketplace. The link also needs a feedback loop for quality assurance.

The tasks underway for this priority include identifying the key contacts within each stakeholder group that can provide links to others within their group, and surveying the participants on their needs for information and their current methods for accessing information.

DISCUSSION

All three priority areas depend on the availability of useful information. If the information is accurate, relevant and organized in an accessible structure, people will perceive value in extracting and applying the information. However, attempts to compile and maintain information within some specific repository fail, precisely because such information quickly becomes incorrect and outdated.

People involved in technology transfer may identify and collect information on the three priority areas, but if the information is not accessible to other stakeholders no value is added or conveyed.

The situation is compounded by taking a global perspective. Active assistive technology programs in Europe, Japan and in developing countries have much valuable information to exchange with North America. Yet the barriers of language, time and distance weight against traditional information repositories such as catalogues and databases.

The only entity capable of maintaining complete and accurate information is the source of the information. Further, the only way to obtain complete and accurate information is to contact that same source. So how do all sources maintain their own information, *yet in a structure accessible* to anyone who wants access?

RESNA members in technology transfer are working with members in information technology to explore distributed information networks like the World Wide Web. If these networks are fully accessible to all potential users, they have promise as viable solutions to the problems inherent in databases. RESNA members from the United States and Canada are working with Europeans within the TIDE project to demonstrate the viability of a distributed network link (2). Specifically, they are working to show how information useful for technology transfer can be maintained locally yet shared globally.

REFERENCES

1. Sheredos, S.J. et. al (1994). "The VA Rehab R&D Technology Transfer Process." In M. Binion (Ed.) Proceedings of the RESNA '94 Annual Conference, Arlington, VA: RESNA Press. 228-230.
2. Fagerberg, G. (1993). "The European Single Market in Rehabilitation Technology." In M. Binion (Ed.) Proceedings of the RESNA '93 Annual Conference, Washington, DC: RESNA Press. 66-67.

ACKNOWLEDGMENT

This work is supported by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education.

Joseph P. Lane, Director
RERC on Technology Evaluation and Transfer
Center for Assistive Technology,
University at Buffalo
Buffalo, NY 14214, U.S.A.
(716) 829-3141;
"joelane@ubvms.cc.buffalo.edu"

SIG-08
Sensory Aids

POINTING KEYBOARD AND TACTILE FEEDBACK SYSTEM FOR BLIND COMPUTER ACCESS

Peter S. Loubal Ph.D., Craig F. Culver, Deborah B. Gilden Ph.D.*, Erik J. Shahoian
TiNi Alloy Company, San Leandro, CA
Smith-Kettlewell Eye Research Institute, San Francisco, CA (*)

ABSTRACT

The goal of this effort is to develop a refreshable "Braille" system to help blind users navigate around a computer screen and to access, input and modify formatted screen and page information, complementing synthetic speech. The envisioned system integrates three distinct input/output devices: a pointing device for navigating the cursor around the screen and providing a self-updating tactile position reference, a chording keyboard for producing alphanumeric output, and a set of tactile pin displays mounted in the keycaps for transmitting alphanumeric data directly to the fingertips of the users.

BACKGROUND

Existing refreshable Braille displays are generally limited to a single row of Braille cells from 20 to 80 characters long. They mimic embossed Braille print, but do not help a blind user achieve a sense of the overall screen arrangement. This makes it difficult to form mental maps because they display only a small part of the screen seen by sighted users. Nearly all newer computer application programs require users to follow one or more cursors jumping between sections of the screen, recognize highlighted text, read pop-up messages, etc. In the absence of tactile screens, any navigation aid that will complement a keyboard and synthetic speech, could substantially improve access to such capabilities.

Our goal is to provide an affordable tactile computer input, output and navigation aid, capable of performing these tasks in a stand-alone fashion, complementing other devices used by blind consumers. In the long run, we hope the device will evolve to the point where it will truly help blind individuals utilize Windows and other graphic display software.

The immediate goals are less ambitious. We expect the product to help in the more mundane and standard tasks of spell-checking, speeding-up the reading of text (words via speech, format information via tactile output), or navigation in spread-sheets. It will also provide a split-Braille alternative for those that are not comfortable or competent with standard cell Braille.

DESIGN AND DEVELOPMENT

Split-Braille Keyboard

Braille writers have chording keyboards. It therefore seems a reasonable hypothesis that a user accustomed to writing Braille characters by pressing chords will readily learn to read Braille information through the same fingertips. A similar approach has been incorporated in a product for two-way communication for the deaf-blind - DIALOGOS - utilizing six tactile stimulators complementing the six keys of a Braille keyboard. These require users to relocate fingertips between reading and writing.

Our initial device utilizes an array of eight tactile keyswitches which serve as the read and write interface for all alphanumeric data. The operator is expected to place four fingers from each hand on the keycaps and keep them there while using the system. Entry of data is accomplished by Braille chording of the keys to produce any required ASCII characters. Reception of data is achieved by feeling, with the fingertips, the chorded rise of a single tactile pin in the center of each keycap. The user will be able to readily switch between the writing and the output reading capabilities. The hands will not need to be repositioned.

A space bar and also additional switches are being considered, to provide the functional capabilities of the Shift, Alt and Control keys. These will probably not be provided with tactile pins, at least initially. As an alternative, the user may simply utilize the eight-key code to input ALT, CTRL and similar commands. The tactile key portion of the project is being developed by United Braille, Inc., San Jose, CA

Screen Navigation

The initial pointing system is made up of two sliding controls, similar to an 'Etch-a-Sketch'. One slider or knob moves the insertion point horizontally along a row of text. The other moves the insertion point vertically from line to line. A pair of potentiometers is linked to these two sliding controls. Such a device most closely resembles a conventional computer pointing devic, such as a mouse, trackball, or joystick, but it has a major distinction in that the axes are isolated from each other, rather than being integrated and that positioning is absolute rather than relative, as in a computer mouse. Any given slider position will therefore reflect a specific position on the screen, so that users are in complete control of cursor positioning. In some application modes it may be preferable to utilize the sliders in a relative manner, for instance to control the reading speed of the speech software or to switch from character-by-character (spelling) mode to word-by-word (reading) mode. We have therefore provide the means to readily switch back and forth between relative and absolute slider positioning.

In the absolute positional reference mode, the user should ideally have a tactile indication of the positicn of the cursor on the screen at all times. The users capabilty to precisely move the cursor at will may, in the initial prototype, not be fully matched by the ability of the sliders to automatically track the motion of the cursor. We expect to develop the active cursor control capability before tackling the more complex problem of how best to have the sliders instantly reflect a new cursor position, i.e. passive cursor control.

The latter capability would be needed, for instance, to help a blind user quickly find a given word, including its location, on the computer screen. We plan to provide the means to insure that the slider indicators remain in step with the cursor at all times at a later stage of the project. The leading candidate for this function is a subsystem containing a pair of stepper motors, controlled by the computer application. The stepper motors would move the slider controls each time a screen event causes the cursor (insertion point) to move. Thus, in normal text entry for instance, as the typing of words causes the insertion point to move to the right character by character, the horizontal position indicator indexes to the right in synchronism, and as the insertion point moves to the next line, the vertical indicator should move downward. Note that most text processing software can automatically align or justify the word positions, especially on the right side of each line, complicating the issue.

Control Circuitry

The device utilizes three embedded 'PIC-type' micro-controllers to integrate the eight key key-pad, two position sensing potentiometers, eight Braille output solenoids, and extra switch inputs and stepper motors, and interface them with an IBM PC computer. A simple serial interfaces is used for communication between the PIC processors. One printer port serves as the connection to the host computer for this system. The 'Lap-Link' form of parallel port interface has been adopted as the external interface convention. This assures a relatively fast interchange of information. When the cursor is moved, either by means of the device or due the application or a screen-reader program, new coordinate and related character information is relayed between the device and the computer.

PIC1 writes data to a parallel port whenever a change on either potentiometersor key inputs is detected. This microcontroller is merely a communications interface. PIC1 receives information on "change of state" from PIC2 via a serial interface. PIC1 is the only controller which can write to the parallel printer port.

POINTING TACTILE KEYBOARD

In order to synchronize writing and reading operations with the Lap Link protocol, PIC1 reads the hand-shake signal from PIC3 in order to know when a read operation is valid.

PIC2 performs analog-to-digital conversion on two potentiometer voltages, reads eight keyswitch inputs, and outputs these data on a change of state to PIC1 via serial interface. PIC2 also decodes combinations of the eight keys and may perform a translation from ASCII to Braille and vice-versa with an internal ROM lookup table.

PIC3 is the only PIC processor which reads the printer port. Its major function is to drive eight solenoids with appropriate data and strobe with a pulse-width modulated signal. This PWM signal decreases heat generation and permits control over tactile force. PIC3 interfaces with a 74LS164 serial to parallel logic device.

Software

Further to the software needed to control the PIC microcontrollers, we have developed a set of routines to help interface the device with an IBM PC computer, under DOS. Programs have been developed to enable the testing of the device, and to help potential users get accustomed to its operation. We have no plans to develop special screen-reader capabilities. This will make it easy for users to keep utilizing their own screen reader systems. As a first step, we expect to incorporate the device and software with the VERT software and hardware package, developed by Automated Systems of Arlington, VA.

EVALUATION

Initial user acceptance testing will utilize the capabilities and resources of the Smith-Kettlewell Eye Research Institute. A number of systems will then be loaned to users for additional beta testing. Sufficient interest has been expressed in this technology that it appears feasible to bring it to product stage within one or two years. This could benefit a substantial number of the 100,000 readers of Braille - and perhaps many others who will learn Braille (or ASCII) as a result of this facilitating device.

DISCUSSION

The developers were very tempted to produce, from the start, a device that would make it easier for blind consumers to utilize the capabilities of Windows- and graphics-based applications, with a rich and complex set of capabilities for interacting with the computer.

The decision to initially concentrate on the less ambitious goal of complementing screen-readers and relatively simple text-processing programs stems from the growing realization that much remains to be discovered. How can we best help blind users keep track of cursor positions? Will consumers utilize the tactile keyboard primarily to read individual characters, or will they find it more uselful as a means to familiarize themselves with the screen layout? Are there other application possibilities, including the market for sighted users, e.g. a more precise joystick, or a computer interface for car drivers, to help spread the development cost and reduce the per unit production costs.

It will take some time to formulate such questions, and longer to obtain answers. The immediate goal is to produce an adequate device that can be manufactured in sufficient quantity. The differences in the needs of potential users are too great to rely too much on laboratory testing. It will be up to the initial users to propose adaptations and modifications to further improve the device

ACKNOWLEDGMENTS

This project is being funded via a Phase II SBIR Grant, under contract with the Department of Education. Dr. A. David Johnson of TiNi Alloy Company acts as pricipal investigator. Dr. James C. Bliss, a businessman with many years of experience in the actuator technology field serves as consultant to the project, to help define and develop a commercially viable product.

Peter S. Loubal, Ph.D.
Consulting Engineer
TiNi Alloy Company
1621 Neptune Drive
San Leandro, CA 94577, U.S.A.
(510) 483-9676

250

STIMULUS DERIVED PERCEPTUAL DYNAMICS IN TACTILE READING

Karsten A. Loepelmann & Eugene C. Lechelt
Sensory Substitution Laboratory, Department of Psychology
University of Alberta, Edmonton, Alberta, CANADA, T6G 2E1

ABSTRACT

A factor limiting tactile reading rates is masking produced by temporal integration of contiguous stimuli. Explanations of this integration have relied on the inferred existence of an "intrinsic persistence" of a representation of the stimulus. This study examines two models accounting for performance on a temporal integration task. One model states tactile persistence is linked to the difference in time between the onsets of successive stimuli, whereas the temporal correlation model is based on correlations of neural responses to stimuli over time. Implications of the findings for tactile reading are discussed.

BACKGROUND

For the visually impaired, the tactile sense represents an alternative means of obtaining environmental information and serves as an ancillary information channel to vision. One difficulty in presenting information rapidly to the skin is produced by the "masking" phenomenon: the perceptual degradation of one stimulus pattern by another when the two are presented in contiguity. The masking effect limits the rate of information that the skin is able to process; masking is likely responsible for limiting the typical reading rates of OPTACON users to around 30 words per minute.

Vibrotactile masking is caused by temporal integration of multiple stimulus patterns (4). Integration has been explained by the mediating influence of an internal representation of the stimulus. This representation or "neural response" is neural activity produced by a physical stimulus. Persistence is the result of the neural response outlasting the inducing stimulus. Temporal integration occurs when the persistence of the leading stimulus overlaps with the visual response of the trailing stimulus. Because the neural response begins decaying shortly after the onset of the stimulus (4), tactile persistence has been conceptualized as governed by the time difference between the onsets of the stimuli (stimulus onset asynchrony, or SOA) and independent of stimulus duration (1).

Although there is support for temporal integration based on tactile persistence and governed by SOA, some studies provide contraindicative evidence. Differences in the inter-stimulus interval (ISI) were found to have an effect on temporal gap detections beyond that predicted by an SOA-based model (5). It is also difficult for an inferred, "intrinsic" persistence account to explain other phenomena. For example, although it is apparent how two brief stimuli can become integrated due to the mediating influence of persistence, it is not clear how a succession of stimuli that comprise a moving pattern can be perceived without producing trails of motion smear. Also, an SOA-based account does not predict the effects of trailing stimulus duration. Because of these problems, the utility of the intrinsic persistence concept comes into question.

Recently, a more comprehensive model of temporal integration was proposed: the temporal correlation model or TCM (3). This model is dependent upon the spatiotemporal contingencies of a stream of stimuli in determining how to code the stimuli. Whether stimuli are perceived as coextensive or disjoint depends on a temporal coding process which correlates neural activity produced by stimuli over time. These correlations are based on regular samples of neural activity; a high correlation results from a high degree of similarity of neural responses over time. The probability of integration increases with the estimated correlation; stimuli will be perceived as integrated when the estimated correlation exceeds some criterion. If there is a sufficiently high correlation the stimuli are coded as coextensive and may be perceived as temporally overlapping or integrated. For example, the curves representing neural responses of stimuli in Figure 1A are dissimilar because the trailing stimulus has a much longer duration than the leading stimulus. As a result, the correlation between the neural responses (indicated by the shaded area) is modest, and the stimuli are likely to be perceived as separate. In Figure 1B, however, because of the greater similarity between the stimuli, the neural responses are more highly correlated and thus are very likely to become temporally integrated. Note than in both cases, the SOA between the leading and trailing stimuli is identical. By delineating the mechanism responsible for temporal integration, a greater understanding of the masking effect may be achieved.

RESEARCH QUESTIONS

The purposes of this study are to (a) investigate the utility of the SOA-based tactile persistence account in predicting performance on a temporal integration task, (b) examine the viability of the TCM in predicting performance under conditions not considered by the SOA-model, and (c) propose implications of the findings for tactile-based reading aids like the OPTACON.

METHOD

Subjects: Four sighted volunteers, two males and two females with no formal OPTACON training, served as observers.

Apparatus: The apparatus consisted of an OPTACON (OPtical-to-TActile CONverter) tactile reading aid, interfaced with an IBM PC XT microcomputer. Each one of the 144 piezoelectric bimorph reeds or "pins" on the OPTACON's tactile display (6 × 24 array, measuring 1.1 × 2.7 cm) can be made to vibrate at 230 Hz via computer control.

Stimuli: The stimuli consisted of a pair of horizontal bars, presented either simultaneously or in succession. Each bar was formed by activating two adjacent rows of stimulators on the tactile display. There was a spatial gap of either 0 or 2 rows of inactive stimulators between the pair of bars. The bars were presented on the uppermost 18 rows of stimulators of the display. To preclude the observers' using the absolute location of the pair of bars as a basis for their response, the location of the bars was varied, and the bar that was presented second appeared either distal or proximal to the first bar; these choices were selected randomly with equal probability.

In Experiment 1, the leading stimulus bars were presented for durations of 5, 10, 20, 40, 80, and 160 ms. The duration of the trailing stimulus was held constant at 15 ms. Note that because SOA is comprised of the sum of the leading stimulus duration and the ISI, values of the SOA ranged from 5 to 260 ms. In Experiment 2, the duration of the leading stimulus was held constant at 15 ms, and the trailing stimulus was presented for durations of 5, 10, 20, 40, 80, and 160 ms. ISIs between stimuli in both experiments were 0, 25, 50, and 100 ms.

Procedure: Each subject sat in front of the OPTACON with the distal pad of his or her left index finger resting on the tactile display. The amplitude of pin vibration was kept at the same level for all observers, in all experiments. Trials were presented using a yes/no procedure, and were self-paced. Half of the trials contained no spatial gap; in the other half, the spatial gap of two rows was presented. Observers were instructed to indicate by pressing buttons whether or not they perceived a spatial gap between the pair of bars. Trial-by-trial feedback was given. Each experiment had a 2 (gap size) × 4 (duration) × 6 (ISI) factorial design. Observers completed 100 trials in each condition. To preclude practice effects, all observers alternated between experiments every 480 trials.

RESULTS

Mean percent correct detections of the spatial gap were obtained for Experiment 1 (see Figure 2) and for Experiment 2 (see Figure 3). To compensate for possible observer bias, responses were normalized using the P(C)max procedure (2).

Experiment 1: As SOA increased, performance declined; also, it appears that longer durations produced decreased performance. Means of gap detection performance were examined using two analyses: a two-way (stimulus duration and ISI) analysis of variance (ANOVA), and an ANOVA examining the effects of SOA. (Due to nonorthogonality of SOA with respect to duration and ISI, it was required to analyze SOA separately.) As expected, a main effect of SOA was obtained (F [22, 73] = 2.428, $p < .05$). Stimulus duration was also determined to be significant (F [5, 72] = 5.728, $p < .05$), as was ISI (F [3, 72] = 4.350, $p < .05$).

Experiment 2: As the duration of the trailing stimulus increased, gap detections increased to a peak, then decreased with longer durations. This observation was confirmed using a two-way (duration of trailing stimulus and ISI) ANOVA. In accord with the TCM, a main effect of duration of the trailing stimulus was obtained (F [6, 72] = 3.895, $p < .05$). ISI was also found to be statistically significant (F [4, 72] = 19.252, $p < .05$).

DISCUSSION

As predicted by the SOA-model of persistence, performance decreased with increasing SOA in Experiment 1. However, there is a degree of variability across conditions having the same SOA value. This discrepancy is accounted for by the TCM: as the duration of the leading stimulus becomes longer than that of the trailing stimulus (and the neural responses become more dissimilar), the two stimuli are less likely to be coded as coextensive, and thus will not be integrated.

In Experiment 2, the SOA-model predicts that performance will be constant across ISI values (note that in this experiment, ISI = SOA); the duration of the trailing stimulus is not taken into consideration. However, the results of this experiment are only consistent with the TCM, which predicts that performance decreases with increasing duration of the trailing stimulus, and that performance decreases with increasing ISI. Further, Figure 3 exhibits a peak around a trailing stimulus duration of 15 ms, which is the same as the duration of the leading stimulus in this experiment. Thus, integration is greatest at the point of maximal temporal similarity, as predicted by the TCM. The results of this research suggest that the TCM has advantages over the SOA-model in accounting for integration performance.

One implication for tactile reading suggested by the TCM is that to lessen the deleterious effects of masking caused by integration, stimuli that are to be coded as disjoint should be presented to maximize the temporal differences between the target pattern and spatiotemporally adjacent patterns. In using the OPTACON as a reading aid though, all stimulus letters are targets, so it would be detrimental to increase perceptibility of one letter at the expense of the preceding and following letters. One possible way to increase efficiency of reading may be to maximize the perceptual separation between letters by altering the duration of presentation of nonattended letters adjacent to target letters.

REFERENCES

1. Craig, J. C. (1982). Temporal integration of vibrotactile patterns. Perception & Psychophysics, 32, 219-229.

2. Craig, J. C. (1984). Vibratory temporal integration as a function of pattern discriminability. Perception & Psychophysics, 35, 579-582.

3. Dixon, P., & Di Lollo, V. (1994). Beyond visible persistence: An alternative account of temporal integration and segregation in visual processing. Cognitive Psychology, 26, 33-63.

4. Evans, P. M. (1987). Vibrotactile masking: Temporal integration, persistence, and strengths of representations. Perception & Psychophysics, 42, 515-525.

5. Loepelmann, K. A., & Lechelt, E. C. (1993). The nature of tactile persistence and implications for tactile reading. In M. Binion (Ed.), RESNA 16th Annual Conference Proceedings (pp. 248-250). Washington, DC: RESNA Press.

Figure 1 Correlations between neural responses of stimuli of differing durations

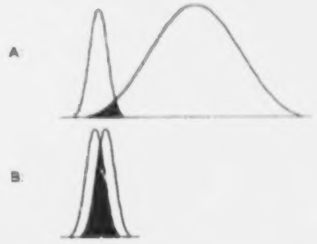


Figure 2 Gap detection performance as a function of SOA

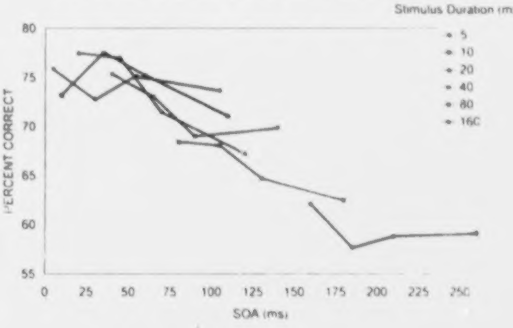
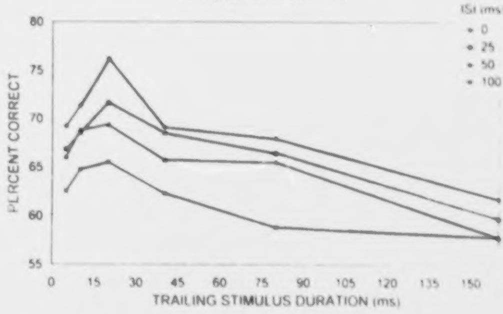


Figure 3 Gap detection performance as a function of trailing stimulus duration



Karsten A. Loepelmann
Department of Psychology
P220 Biological Sciences Building
University of Alberta
Edmonton, Alberta, CANADA T6G 2E1

Away From the Maddening Crowd

MICHAEL E. SWORDS
SWORDS AND ASSOCIATES

ABSTRACT:

A consumer presents an interim summary of his techniques for remediating an "Auditory Processing Deficit."

BACKGROUND:

Noise is an industrial pollutant. It affects body mind and spirit. Long term effects can be physically and mentally damaging. Signal and noise separation is an increasing problem. For people with figure-ground hearing issues separating alerting, orientation, and speech signals from background sounds can be exhausting. Ambient noise put stress on the central nervous system. Stress energizes hormonal defense mechanisms. Constant stress can influence cultural integration and personality.

IMPLICATIONS:

For consumers with less than commensurate figure-ground separation abilities reducing noise increases hearing clarity, relaxes communication, reduces stress, improves socialization and,increases the probability of success in academic and professional settings. Social standing and self-esteem are keyed to success in school and at work. Lowered strain for clear hearing can moderate production of neurochemical defense hormones. Attention, emotional control, socialization, and cultural integration may be influenced.

THE PROBLEM:

Prolonged exposure to noise habituates adaptive responses. Habitual cognitive responses alter behavior. The problem is a human one, but it is intense for those with noncompetitive hearing traits. This consumer has a severely reduced ability to discriminate sounds. When speech signals and background are equal, hearing requires Herculean effort. Conductive mechanisms are reasonably intact. Continual amplification is inappropriate.

Many activities of daily living require low level signal-noise discrimination. Beside discrimination of speech from noise, audition is constantly taxed from more oblique angles. Typical subtle decoding tasks included in the acoustic stew are singing voices from background music, TV dialogue from laughter, car engine performance from traffic noise. Nature provides its own a symphony of signals for discrimination. Subconsciously, these sounds give ques for orientation and balance. Birds chirping, crows crowing, and dogs barking are typical domestic signals needing separation from other background sounds.

The total absence of sound creates auditory deprivation and psychological problems. Solutions to the problem must find combinations of signal enhancement and noise reduction, not under or over stimulating the central nervous system.

DISCUSSION:

Creating a safe haven from the avalanche of noise is a challenging and ongoing task. Every minor reduction of signal-noise discrimination tasks helps. Here is brief summary of designed and implemented strategies to date.

Household noise sources are eliminated or managed. A few examples are digital clocks replace mechanical one, meditative silence displaces the companionship of background music, noisy appliances (like a computer printer) are shut off when not in use. Unneeded phone ringers are silenced.

Noise infiltration is reduced by keeping windows and doors shut (whenever practical), storm windows are left up all year round (opening screened doors provides enough fresh air for comfort), foam weather striping tape around the storm windows increases the acoustical seal, ear plugs help quiet the neighbors lawn mowers roar.

Ear plugs are invaluable outside too. Just as more severe weather calls for heavier coats, more severe levels of noise call for greater attenuation. High attenuation ear plugs and acoustic ear muffs reduce the acoustic impact of high noise activities, like running a chain saw. The same plugs by themselves cancel noise generated by a lawn tractor. Medium attenuation plugs eliminate trivial and annoying background sounds. Mild ones raise the signal to noise ratio when listening to speech in noisy places. They force a greater reliance on speech reading. Speakers enjoy the complement of rapt attention to their words.

Attenuation creates a risk of not hearing the safety warnings of alerting sounds. Inside loud smoke detectors, door bells, and telephone ringers easily offset this issue. Outside visual vigilance offsets this risk. Greater reliance on visual cues forces focuses awareness. Greater awareness is the best defense against injury.

Outside the home the first line of defense is the inverse square law. All sound diminishes in intensity as listening distance increases. Stepping just a few feet away from exhaust ducts, noisy computer printers, competing conversations, heavy machinery, or a blaring radio drops the acoustic dosage. Long runs of impact printing are scheduled for coffee breaks.

Another line of defense is prudently choosing conversational settings. This dramatically diminishes the daily auditory load. Restaurants and retail stores in off hours are at least two-thirds quieter than at peak hours. Churches, quiet rooms in libraries, museums, and closed door offices are generally sanctuaries. The upper floors of buildings are away from street noises. Elevator traffic and operation sounds lessen as one moves down the hall. Density stops sound. Concrete and earth surrounding basements dramatically dampen outside noises. These are natural acoustic shelters.

A third line of defense against the onslaught of industrial noise is social management. For critical communication, the written word substitutes for the spoken word. "Tips for Talking to the Hard of Hearing" is a one page handout supplied by a local hearing aid vendor. In many cases the tangible reinforcement has more lasting value than a verbal explanation. New social contacts get this sheet by mail, most times before a first meeting. People that can relate, generally form successful relationships. Others, blend into the social noise.

A telephone amplifier helps process soft voices and weak connections. Except for the softest voices, the volume control remains at the lowest setting. Sustaining amplification for more then a few minutes hurts the ears. The effect is like a sun-burn. No consequences from the exposure are immediately apparent. Pain and discomfort comes a few hours latter. Just like an overdose of the sun, it takes a few days for the "redness" and sensitivity to fade.

A high quality, dual earphone, telephone headset increases signal processing capabilities by several orders of magnitude. Twice as much information gets to the brain. Leather covers and foam cushions on the speakers cut background noise. Using this head set for just a couple of days, made all other phone receivers sound like a tin can on the end of string. The headset--and a pin drop quiet listening environment--raises auditory processing ability. Processing speech through the headset increased awareness and impact of subtle ques. Now a chronic social fault "interrupting" (actually not hearing quiet ques) has mostly evaporated.

Hearing assistance devices have serious shortcomings. Personal communicators are simplex. Only one person can talk. Dialogue is limited. Social introject is awkward. The appliance is clumsy, especially to the uninitiated. Where noise is not meticulously managed, omnidirectional microphones pick up and amplify noise. They are useless in public settings, like restaurants. Clip on microphones rustle against clothing, creating more noise and distraction. Most commercial broadcast systems, FM and infrared, seem to have either internal electrical noise (especially hum) and/ or receive spurious radio frequency noise.

Frayed nerves act like antennas for noise. Planed listening respites, especially after critical communication sprints, are essential. A good nights sleep increases auditory reserves and staying power.

Michael E. Swords
Swords and Associates
5505 Lomond Avenue
Downers Grove, IL 60515
© 1995.

SIG-09
Wheeled Mobility and Seating

INTERFACE MECHANICS IN PROSTHETICS: A SYSTEM FOR ANALYSIS

JE Sanders, AJ Dralle, R Okumura, G Turkiyyah, HD Jang, D Lam,
D Berglund, R Reed, G Hwaung, and R Miller
Center for Bioengineering and Department of Rehabilitation Medicine
University of Washington, Seattle, WA 98195

Abstract:

A system for biomechanical analysis in lower-limb prosthetics is described. The system has both experimental and analytical components. Instrumentation includes a thirteen-transducer interface stress measurement and data acquisition system, a six-axis prosthesis force sensor, and a silhouette-imaging scanner. Principal analytical components include a finite element model and optimization schemes for custom design of interface materials and socket shape. This combined experimental and analytical system will be used to facilitate the improvement in design of prosthetic componentry and materials to enhance the quality of life for lower-limb amputees.

Introduction:

The mechanical interaction between the residual limb and prosthetic socket is of critical importance to a lower-limb amputee. The health of the soft tissues as well as the stability of gait are affected by the interface stress distributions.

An approach to the understanding of interface mechanics and the role of patient characteristics and prosthesis design in them is through experimental and analytical investigation. Experimental investigations that potentially provide insight include measurements of interface normal and shear stresses, prosthesis forces and moments, and residual limb geometry. Interface stress sensors in the socket allow the measurement of normal and shear interface stresses during standing and gait. These stresses are important in socket and componentry design. Sensors in the prosthetic shank allow study of the forces and moments delivered to the socket as well as analysis of the gait biomechanics. A prosthesis force sensor is essentially a 'force plate' within the prosthesis. Residual limb geometry measurements are used for socket design but also potentially can be used to investigate residual limb geometry fluctuations. Because geometry fluctuations are such an important issue in prosthetic fitting, insight into them can be of important use in socket design.

An analytical tool that shows potential utility in prosthetics is finite element (FE) analysis. Through sensitivity analyses, FE analysis can provide, in a dry-lab setting, insight into amputee patient characteristics and prosthesis design features that strongly affect interface stress distributions. In the long-term, FE analysis potentially can be used in individual amputee socket design.

Below, instrumentation to measure interface stresses, shank forces and moments, and residual limb geometry are described. Data and interpretations are presented. Analytical tools for application to socket optimization are also described.

Methods:

Interface stress measurement system: A system to measure interface stresses in three orthogonal directions at thirteen socket sites was developed (**Figure 1**). Custom-designed transducers [1] are positioned through holes in the socket so that they are flush with the inside socket surface. A digital data acquisition system was designed to store the data to a PCMCIA card housed in a fanny pack unit [2]. In addition to the 39 channels from the interface sensors, the system also stores the force and moment data from the prosthesis six-axis sensor (see below), thus a total of 45 channels are monitored. Batteries are also housed within the unit, making the entire 45-channel system portable. The mass of instrumentation on the socket is 0.47 kg, while that in the fanny pack is 2.4 kg. Approximately 5 minutes of data can be collected continuously.

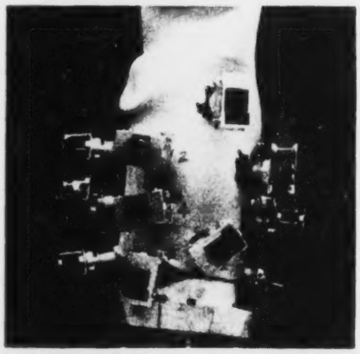


FIGURE 1: An instrumented prosthesis. Thirteen transducers are placed in mounts on the anterior, lateral, and posterior socket surfaces.

Six-axis sensor: A custom sensor was designed to measure forces and moments in three orthogonal directions applied immediately beneath the socket (**Figure 2**). The sensor is of dimension 10.2 cm

257

diameter and 1.9 cm thickness and of mass 0.37 kg (including signal conditioning electronics). Connector plates attach the top of the sensor to the socket and the bottom to a standard modular alignment device via the standard 5-cm bolt-circle configuration. Strain gages mounted on beams and configured in six Wheatstone bridge circuits are used as the sensing elements. Because each of the six measurements is independent, the three forces and three moments can be determined. By loading the sensor under known combinations of load in a bench test set up, a 6 x 6 calibration matrix relating forces and moments to the bridge outputs was generated. The matrix is used to process data collected on amputee subjects into forces and moments in a known coordinate system.

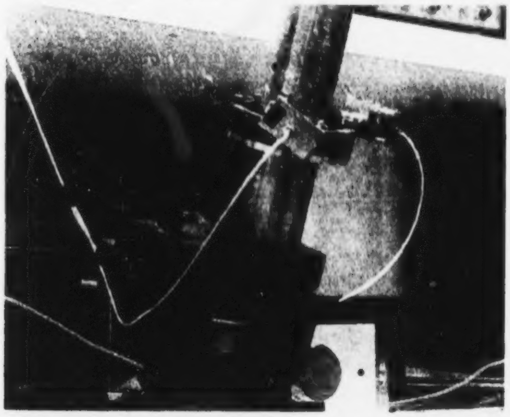


FIGURE 2: Six-axis sensor. The sensor is positioned in an apparatus for calibration.

Silhouette scanner: A silhouette scanner was designed to measure the external residual limb geometry in approximately 1 second with 0.5 mm resolution [3]. The purpose of developing a scanner with these specifications was to allow the investigation of residual limb shape changes that occur either diurnally or over the long term. Shape changes complicate socket fitting.

The scanner measures residual limb geometry using a silhouetting method. A CCD camera mounted on a cantilever beam rotates around the residual limb, capturing 17 digital images for 220 degrees of the rotation (**Figure 3**). The images are used to reconstruct the residual limb shape. Contour reconstruction is conducted in axial cross-sections and then those contours are used to form the three-dimensional residual limb shape.

Finite element model: A finite element modeling methodology to analyze interface mechanics of any given residual limb shape and prosthetic socket shape was developed. Residual limb shape data from the scanner, socket shape data from a socket digitizer, and bone shape data from a parametric analysis are used to establish the model geometry (**Figure 4**). Data from the six-axis force sensor are used to prescribe force boundary conditions on the bottom of the model. Several nonlinearities are considered in the model, including a nonlinear interface that allows large displacements (pistoning) between the residual limb and socket. Based on interface stress results from the model, an optimization scheme is being generated to design socket shape and materials for individual amputee patients.

FIGURE 3: Silhouette scanner. Images are taken with a CCD camera as it circles the residual limb.

Interface Stress Results:

In **Figure 5a,b** the resultant shear directions on the socket during early stance phase from a unilateral below-knee amputee subject are shown, as indicated by the arrows. The bold numbers next to each arrow indicate the magnitudes of the normal stresses (in kPa) and the lower numbers indicate the resultant shear stresses (in kPa) on the transducers.

Interface stress distributions changed for sessions conducted at least 30 minutes apart. **Figure 5a** and **5b** are from sessions several weeks apart. The subject lost weight between the two sessions, and that is exemplified in the distribution of the stress. The subject complained of a sensation of 'bottoming out' during the second session (**Figure 5b**). Shear stresses are higher distally than in the first session and the upper part of the socket is providing little support (**Figure 5a**).

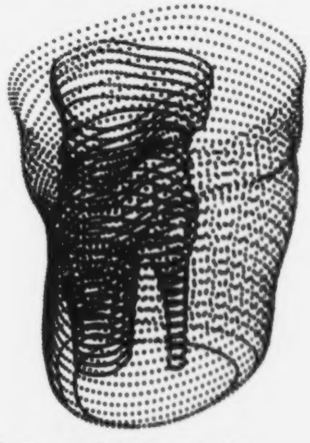
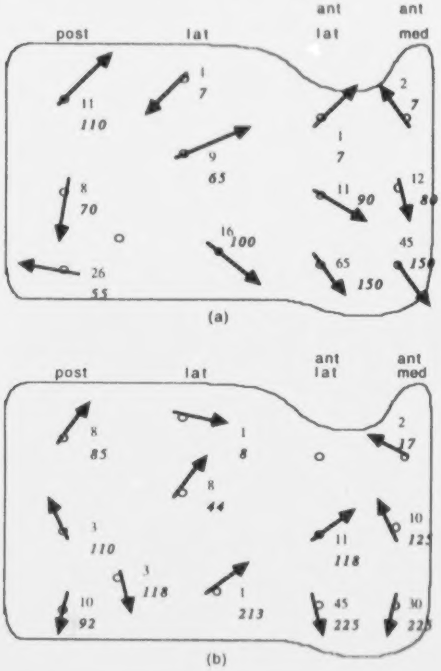


FIGURE 4: Bone and socket geometry.



(a)

(b)

FIGURE 5a,b: Interface normal and resultant shear stresses during early stance phase from two different sessions. The socket is cut along an antero-medial line and 'upwrapped'.

Some similar trends were found in data collected from three different subjects. First, interface stress data showed double-peaked curves, where the two peaks corresponded approximately to the two peaks in the axial force from the six-axis sensor. Transducers measured a much lower stress during swing phase than during stance phase; typically distal sites were completely unloaded. Resultant shear directions on the upper region of the socket near the brim were directed upward during mid-stance. Resultant shear stresses on the anterior surface tended to be directed medially.

Discussion:

The described experimental and analytical systems provide data to improve the understanding of residual limb/prosthetic socket interface mechanics during standing and walking.

The results presented here provide some interesting insights:

* Though initially the upwardly-directed resultant shear stresses near the socket brim shown in **Figure 5a,b** might seem illogical since walking is a downward motion, the finding can be explained by considering the tissue mechanics involved. During prosthetic limb loading, the bone is forced downward into the socket, displacing soft tissue in the residual limb upward.

* The trend of resultant shear stresses on the anterior socket surface being medially-directed was likely due to the tibia being forced into the socket relief for the tibial crest. The high bending moment of the stump in the socket in the sagittal plane contributed to the resultant interface stresses.

* Differences in measured interface stresses from one session to the next provide data that substantiates the importance of residual limb shape changes in affecting interface mechanics. More research attention should be focused on shape differences.

Acknowledgements:

This research was supported by the NIH (grant number R01-HD31445), the Washington Technology Center, M+IND Inc. of Seattle, and the VA.

References:

[1] Sanders JE and Daly CH: *IEEE Trans. Rehab. Engi.*, 1(2): 79-85, 1993.
[2] Smith LM: MSE dissertation in Bioengineering, University of Washington, 1994.
[3] Schreiner RE: MSE dissertation in Bioengineering, University of Washington, 1993.

Corresponding Author:

JE Sanders PhD
Center for Bioengineering, WD-12
University of Washington
Seattle, WA 98195

LONG TERM RESULTS OF POSTURAL POSITIONING

Jaimie White, OTR; Yvonne Longoria, OTR; Chris Bailey, RPT
and Charles J. Laenger, PE
Oklahoma Department of Human Services

ABSTRACT

Conservative postural positioning practitioners are reluctant to claim that seating has "corrective", or orthopedic" effects. While logic points in this direction, statistically significant results on which to make firm declarations do not exist. In the absence of such information, it is vital that well documented, long term cases be permitted to speak for themselves. Four cases involving severely disabled clients that have received serial custom-contoured seating systems over four to six year periods are presented herein. The results indicate that postural positioning systems, coupled with appropriate therapy, can produce "corrective" or "orthopedic" results.

BACKGROUND

Case #1

BR exhibited incredibly strong muscle tone and spasticity. He was very difficult to feed, to position and to assist in activities of daily living. He was apparently congenitally deaf and never developed communication skills although it is believed that he recognized family members and others. Attempts to seat him in a planar system were repetitively disastrous. He was injured by tight belts and hard surfaces and poor distribution of pressure. He was confined to bed for repetitive bouts with pneumonia which was probably induced by aspiration. See Photo #1. Custom-contoured seating development for this client began in 1988.

Case #2

RC had been supine for 30 years; he was diagnosed as having leukodystrophy. He had very low muscle tone and severe deformities that had been present for many years. See Photo #2. He was non-verbal and showed almost no understanding of cause and effect. Development of custom-contoured seating for this client began in 1990.

Case #3

MC is the brother of RC. He too had developed severe deformities and had been supine for almost 30 years. See Photo #2. Development of custom-contoured postural positioning began in 1990.

Photo #2. RC and MC in Contour-U cushion system after Bazata-Jones and Conyers in 1990.

Case #4

Cerebral palsy is the primary diagnosis for KB. She had soft tissue contractures and severe scoliosis and demonstrated athetosis that rendered her hands and arms almost useless. At 16 years of age she was provided with a planar postural positioning device. See Photo #4. Custom-contoured seating development for this client began in 1990.

260

RESULTS - POSTURAL POSITIONING

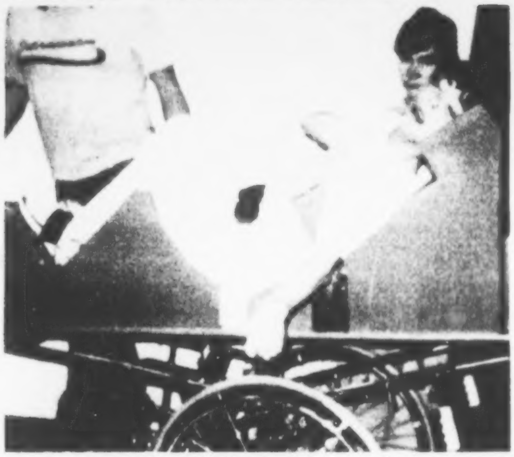


Photo #4. Inappropriate planar seating system - 1988.

OBJECTIVES

In all four cases, the objectives were to accommodate deformities, protect soft tissue and to position for function. A retrospective objective was to monitor and report long-term results.

APPROACH/RESULTS

Case #1, BR

A custom contoured Beadseat system with a soft spot to accommodate very bony spinal prominences was completed in May of 1989. This system was mounted in an Enduro tilt-in-space manual wheelchair. A large custom-made headrest, custom anterior-lateral supports and knee blocks were included. Numerous repairs and modifications were made to the system until December of 1994 when a new Pin Dot Contour-U system was fabricated and provided. See Photo #5. BR was moved from an institutional setting to a group home in 1991. He has received excellent care, attention and therapy in this setting. He is much happier and more pleasant today.

In years preceding acquisition of the Beadseat system, BR was hospitalized every 4-6 weeks with pneumonia of soft tissue breakdown. Much of his health problem was caused by aspiration that occurred during feeding-which was a most time-consuming and unpleasant process. The custom-contoured system helps BR to relax during feeding. The tilt-in-space feature helps to position him better for feeding and resting. The system reduces the frequency of transfers and prevents damage to the hands and arms due to spasticity and flailing of the hands and arms. Development of the ability to relax more has permitted elimination of knee blocks. The headrest has been made much smaller and if may be possible to eliminate the special anterior supports. Fabrication of a new Contour-U seating system is in progress. The client has gained 25 pounds in the past two years. Much of the improvement of this client is attributable to the therapy and care that he is receiving in the home.

Photo #5. BR in new Contour-U System.

CASE #2, RC

This client received a tiltable, linear positioning device (after Bazata, Jones and Conyers, in 1990. See Photo #2. The custom-contoured cushions were Pin Dot Contour-U. He received a new Contour-U system and was seated upright in November of 1992. He currently is much more responsive, has gained 17 pounds, vocalizes more and has not had an illness requiring hospitalization in 4 years. He now uses an augmentative communication device.

CASE #3, MC

This client received a tiltable, linear positioning device in 1990. See Photo #2. This system included Pin Dot Contour-U cushions. In 1992, a special foam-in-place fixture for extending and abducting the legs was added to the system for part-time use. In December of 1994, MC was seated upright in a tilt-in-space wheelchair with Contour-U cushions. He is now upright for one hour multiple times daily. He is transported in a van in an upright position.

Photo #6. MC in upright position.

CASE #4, KB

In of 1990, KB received a Contour-U seating system mounted in a manual tilt-in-space wheelchair. In December of 1992, the Contour-U cushions were remade to conform with changes in posture and size. Her position in space was changed to bring her more upright as she became less fearful of falling. The old Contour-U cushions were mounted in a rolling commode seat. KB now drives a powered wheelchair.

DISCUSSION

All of the individuals described made significant progress in postural alignment, position in space orientation, and use of arms and hands. RC, MC, and KB achieved success because their deformities were "positional" in nature. BR's success has only been limited by the severity of his spasticity.

RESULTS

It is often difficult to determine if deformities are the result of poor positioning or spasticity. The use of serial custom-contoured seating systems allows the team to make this differentiation. Those individuals with soft tissue contractures and athetoid movement disorders appear to have potential for dramatic changes in seating posture. The reliance on improvement in joint range of motion is inadequate! Improvements in weight gain, respiratory health communication and, above all, comfort are far more important.

Photo 7. KB drives powered wheelchair and uses communicator.

REFERENCES

White, J; Jennings, B; and Laenger, C; Serial Custom-Contoured Seating for An Individual with Athetoid Cerebral Palsy, RESNA '93, June 12, 1993.

Jennings, B; White, J and Laenger, C; Postural Positioning Coupled with Therapy RESNA '93, June 12, 1993.

ACKNOWLEDGEMENTS

The Oklahoma Department of Human Services, Developmental Disabilities Division, provided funding for the labor and equipment involved in these cases. The Mervin Bovaird Foundation provided funding for development and implementation of modern techniques for postural positioning at this rehabilitation center. The families of these clients have been faithful, cooperative and supportive.

Jaimie White, OTR
Oklahoma DHS/DDS
The Laura Dester Center
1427 East Eighth Street
Tulsa, Oklahoma 74120

INDEPTH ASSESSMENT OF A POSTURAL POSITIONING PROGRAM

Yvonne Longoria, O.T.R.; Chris Bailey, RPT;
Charles J. Laenger, PE; Jim Lee, ME; and Larry Brock, Volunteer
Kaiser Rehabilitation Center, Tulsa, Oklahoma

ABSTRACT

This rehabilitation center has had a postural positioning/seating program for nine years. During that time the postural positioning and seating needs of 257 clients have been assessed. Approximately 45 of these clients have been re-assessed in the past two years. See Figure 1. A total of 206 systems have been delivered while 50 remain in process. Forty-six were not completed for various reasons. Initially in 1986, this center began a basic seating program in which commercially available equipment was prescribed. In 1988, equipment became more customized and the first contoured system was completed. Since that time, the number of contoured and customized systems have significantly increased. Average delivery times have been 2-5 months from date of evaluation. Contour-U systems sometimes requiring 2-3 remakes may take up to 12 months before delivery is complete. Acquisition of this data has helped this center to research various avenues to improve quality, minimize delivery time, and increase customer satisfaction.

BACKGROUND

The rehabilitation engineering center began a formal postural positioning program in 1988 when its engineer attended a basic course sponsored by the University of Tennessee at Memphis. The existing postural positioning team consists of the following: occupational therapist, rehabilitation engineer and rehabilitation technician. Ad hoc members consist of staff physical and speech therapists and non-staff, community based therapists. In early years, therapists from other departments were borrowed as needed. In 1989, the first "customized" systems were completed and consisted of 2 planar, 2 Beadseat (BS), and 2 foam-in-place (FIP), with additional commercial and custom modifications as needed. Both manual and powered wheelchair bases were used. See Figure 2.

With the closing of a local state institution and a court order mandate to provide community based services for the multihandicapped, the need for postural seating significantly grew. In 1990, three clients from within this institution received contoured seating systems. These clients presented with severe deformities and/or abnormal tone which significantly limited postural stability and function. The goal of the contoured system was to provide postural stability, maximize comfort, and improve function for each individual client. As the need for customized seating grew, the need for therapeutic involvement increased. In 1993, an occupational therapist with seating experience joined the rehabilitation engineering department full time.

This facility has attempted to remain cognizant of state of the art technology by upgrading and improving its skills, developing new seating techniques and components and providing services to a wide range of clients. An indepth evaluation including client caretaker interview, assessment of the client on the mat and in fitting chairs and a trial use of equipment is performed for each individual. The indepth assessment determines ways and means for improving seating quality, fit, efficiency, and customer satisfaction, while cutting costs and delivery time. Through trial and error assessment and interview methods many issues come to surface which must be addressed. The seating assessment is a team approach recognizing client and caretaker needs as primary considerations. Results of the evaluation and interview and subsequent study by the team are used to determine seating goals, methods and specific equipment based on individual client needs. This information is included in a letter addressed to the physician and funding source. A series of fittings and trial use of the equipment completes the final process before delivery of the equipment.

OBJECTIVE

The objective of this study was to acquire data on numbers and types of seating evaluations and to identify methods and procedures in the postural positioning program that require improvement, further documentation, and change.

METHODS

All Rehabilitation Engineering charts were screened. Only those identified as seating assessments received review and documentation. Data gathered included client name, diagnosis, funding source, evaluation date, delivery date, wheelchair frame type, wheelchair insert type, custom modification, re-evaluation date, re-evaluation recommendations, re-evaluation delivery date. Phone interviews were conducted on 117 charts. These interviews were to gather information regarding quality and appropriateness of seating systems delivered. Forty-five re-evaluations were implemented as a result of the client/caretaker interview. Revaluations were performed for a variety of reasons such as client growth, postural changes, equipment breakdown, etc.

RESULTS

The following seating systems have been completed since 1986. 1) Custom planar 139; 2) Foam in place (FIP) 4; 3) Beadseat (BS) 18; 4) Silhouette 22; and 5) Contour-U 42. Results of the study indicate a significant increase of Contour-U systems the past two years. See Firgure 3. Ten clients who were re-assessed were recommended for Contour-U systems vs. their existing custom planar, FIP, or BS system. Reasons for recommendation of a Contour-U were as follows: (1) To provide better fit, comfort, and weight distribution. BS and FIP do not allow for time to adequately position a client and are difficult to mold and maintain a desired shape. Custom planar or a combination of those listed also are very difficult to adequately and comfortably seat the client with severe deformities and/or abnormal tone. (2) Improved quality and resiliency of the system. BS and FIP life expectancy is limited. (3) Improve remake quality and fit, when a remake is indicated due to improper fit.

It was found that the average delivery time for a Contour-U was 3-5 months. Of the 38 Contour-U systems delivered in 1993 and 1994, there were 15 clients requiring a remake. Five were delivered after the first remake with delivery times ranging from 3-12 months. Four were delivered after the second remake with an average delivery time of 12 months. Two Contour U's were remade at no charge to the client after the expired warranty date. Four remain in the fitting process.

FIG. 1, SEATING EVALUATIONS

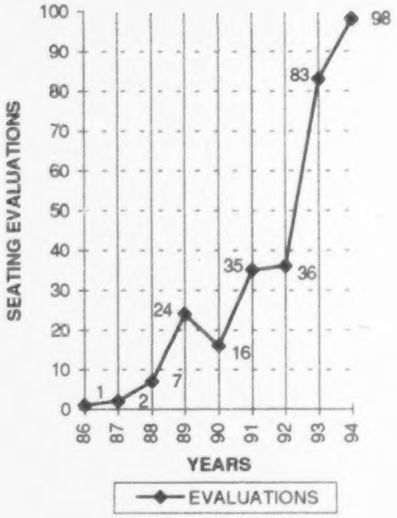


FIG. 2, WHEELCHAIR FRAME TYPES DELIVERED

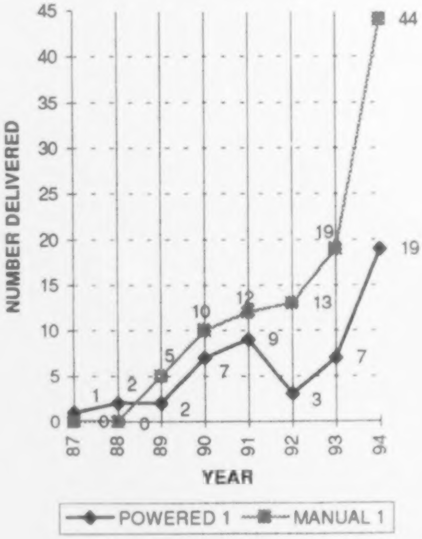
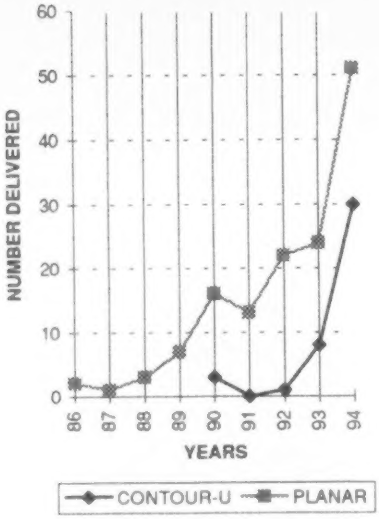


FIG. 3, SEATING SYSTEMS DELIVERED



DISCUSSION

Data indicates that Contour-U is far superior to BS, FIP, and custom planar systems (sometimes using BS or FIP inserts) for the reasons of increased comfort, fit and durability when seating clients with severe deformities and abnormal tone. However, data also indicates delivery time and the number of remakes for Contour-U have been less than satisfactory.

Therefore, the following are new procedures that have been implemented for the purpose of recognizing and tracking those problems already identified and foreseeing future problems: (1) One month, 6 month, 12 month followup calls to improve quality assurance. (2) Established new methods to mold and cast. (3) Trial fittings in Flamingo fitting chair to identify necessary angles and support surfaces most appropriate for actual fitting. (4) Recline of fitting chair during trials and actual moldings to facilitate and maintain desired posture. (5) Follow up to various pay sources for seating recommendations that seem to get "lost in the shuffle." This facility continues to attempt to identify consistent problems and implement new methods for improving first time fit and reducing service delivery time.

Areas in which clients caretakers, and rehabilitative team members expressed increased satisfaction and progress with improved sitting posture were as follows: (1) respiration; (2) comfort; (3) increased time in upright sitting; (4) independent mobility, i.e., powered; (5) augmentative/alternative communication via computer, or switch access; (6) environmental control/access; (7) decreased incidence of skin problems; and (8) increased socialization. These areas have been identified as needing future indepth study and documentation in order to provide better outcomes and benefits of postural positioning.

REFERENCES

Laenger, C; Bailey, C; Longoria, Y; Lee, J; Custom-Contoured Anterior-Lateral Supports, RESNA '93, June 12, 1993.

White, J; Jennings, B; and Laenger, C; Serial Custom-Contoured Seating for An Individual with Athetoid Cerebral Palsy, RESNA '93, June 12, 1993.

Jennings, B; White, J and Laenger, C; Postural Positioning Coupled with Therapy RESNA '93, June 12, 1993.

Laenger, C; Gainor, M; and Lee, J; Knee Block Fitting Jig, RESNA '93, June 12, 1993.

ACKNOWLEDGEMENTS

The Mervin Bovaird Foundation provided funding for this extended study, assessment and improvement program. This foundation has provided long-term support for development of seating and mobility services at this rehabilitation center.

Yvonne Longoria, OTR
Rehab Engineering Department
Kaiser Rehabilitation Center
1125 South Trenton
Tulsa, Oklahoma 74120-5498

SEATING AND MOBILITY FOR A VENTILATOR-DEPENDENT MUSCULAR DYSTROPHY ADULT

Charles J Laenger PE, Yvonne Longoria OTR, Chris Bailey RPT
Kaiser Rehabilitation Center
Tulsa, Oklahoma

ABSTRACT

Loss of strength and decreased range of motion rendered this 27 year-old client incapable of operating his joystick-controlled wheelchair. Severe, progressive deformities made breathing very difficult and made use of supplemental oxygen mandatory. Successful trials of a puff-sip controlled powered wheelchair justified acquisition of a powered wheelchair with powered tilt-in-space seat. A custom-contoured Contour-U seating system with soft spot for ischial tuberosities was modified by technical personnel and family members. The client now attends college.

BACKGROUND

The vocational rehabilitation counselor was reluctant to acquire a sophisticated powered wheelchair and custom seating system without assurances that they would benefit the client. Severe deformities and weak condition of the client justified these doubts. See Photo #1 and #2. Initial trials with a puff-sip simulator were unsuccessful. The client practiced "blowing bubbles" for four weeks until he developed mouth closure and sufficient strength to operate the puff-sip simulator. The client was placed in a vacuum-consolidation-of-beads fitting chair and fitted for comfort and trunk stability to facilitate breathing.

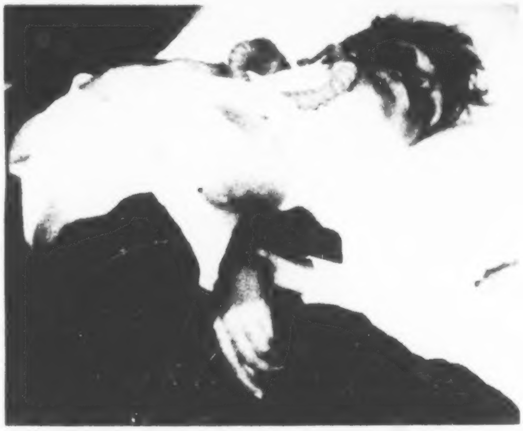


Photo #1. Dramatic scoliosis; rib cage threatens to penetrate skin.

Photo #2. Client attempts unsuccessfully to use puff-sip control.

This position also provided a suitable head position for vision for driving and for good pressure distribution. A one-hour tolerance test was made. A proposal for a pneumatically operated powered wheelchair with powered tilt-in-space custom-contoured seat was made.

OBJECTIVE

The objective was to provide independent mobility and seating that would enable the client to successfully perform as a college student with minimal assistance.

APPROACH

The client was permitted to try to control a puff-sip operated E&J system. He sat in his old wheelchair, supported with pillows and blankets, and a hand-held tube connected to the E&J control system was presented to him by a staff member. He could operate the "sip" or negative pressure pneumatic switch but could not operate the "puff" or positive switch system. He was sent home with a short rubber tube and instructed to blow bubbles in a glass of water; initially, he was unsuccessful. But after several weeks he developed sufficient strength, timing and mouth closure to blow a "string" of bubbles. He tried again to operate the E&J puff-sip wheelchair control system, but failed again. He was then presented with a MED puff-sip simulator. He could operate the "turn" functions which required low levels (about 5" of water) positive and negative pressures. But he could not consistently operate the "start" and "stop" functions of the simulator. He took the simulator home; after several weeks, he developed the capability for operating all functions consistently. He returned to the rehabilitation center where he demonstrated the capability for operating the E&J wheelchair with puff-sip control. See Photo #3.

Photo #3. With two months of puff-sip training and development and a custom-contoured seating system, the client drove successfully.

The client was transferred into a Flamingo chair which utilizes vacuum-consolidation -of-beads bags which can be shaped to the contours of a subject. With the chair seat tilted about 30° and a seat-to-back angle of about 120°, the system was molded to accommodate the deformities of the client. Mr. P. found this posture and positioning to be comfortable and to permit respiration with less effort. After about 30 minutes, the skin on his skinny buttocks showed redness that faded in less than 10 minutes. He tolerated the chair for another 30 minutes.

A proposal was written to Oklahoma Rehabilitative Services for a power drive, puff-sip controlled wheelchair with powered tilt-in-space seat both controlled via the puff-sip operated system programmer. A custom-contoured Contour-U system was also proposed. The Pin Dot seat cushion was made with a 5" diameter "soft spot" to protect soft tissue overlying the ischial tuberosities. Initial trials indicated that a wider "soft spot" was required. The remake proved to be too firm. At the request of the client, the soft spot was cut out and replaced with ½" of Akton Viscoelastic Polymer gel. The client returned home for a programmed tolerance-development period. This proved moderately successful. The parents removed the gel in the soft spot cavity and replaced it with a section of a Roho cushion. See Photo #4. The client can now tolerate the seating system for eight hours!! He drives the wheelchair and attends community college with assistance.

DISCUSSION

This case demonstrates that even the most severely disabled clients may benefit from technical intervention. The conservative approach where trials are used to justify or validate further action can circumvent disappointment and waste. More importantly, these indicators are useful in convincing funding sources of feasibility and justification for serving the client.

REFERENCES

Bazata, C; Jones, K; and Conyers, B; The Seating Challenge, Pin Dot News, circa 1988.

White, J; Jennings, B; and Laenger, C; Serial Custom-Contoured Seating for An Individual with Athetoid Cerebral Palsy, RESNA '93, June 12, 1993.

Jennings, B; White, J and Laenger, C; Postural Positioning Coupled with Therapy RESNA '93, June 12, 1993.

ACKNOWLEDGEMENTS

The Mervin Bovaird Foundation has provided long-term support for development of seating and mobility services at this rehabilitation center. Oklahoma Rehabilitative Services has served severely disabled clients faithfully and with good judgment. The client discussed in this paper, along with his wonderful parents, is gutsy and smart.

Charles J. Laenger, PE
Manager, Rehab Engineering
Kaiser Rehabilitation Center
1125 South Trenton
Tulsa, Oklahoma 74120-5498

Custom Head Support for a Pediatric Quadriplegic with Asymmetrical Neck Tone

Kevin Caves, Lori Okamura, Carin Adams
Los Amigos Research and Education Institute
Rancho Los Amigos Medical Center

Abstract

This paper describes the design, development and use of a custom head support for a 7 year old male with a C1-2 complete spinal injury, asymmetrical neck tone and a history of skin breakdown on his head and neck. The system consists of a rigid head ring lined with a custom fabricated Roho air cushion. The new head rest allowed the child to sit up to 14 hours per day in 4-6 hour blocks. Also, over a four month period he had no incidence of skin breakdown on his head or neck.

Background

Antre is a 7 year old, African-American male who sustained a C1-2 complete spinal cord injury, in November, 1990. He is ventilator dependent and cannot independently maintain his head in an upright position. He is seated in an Invacare Arrow power wheelchair with a LaBac sliding back recliner, which he drives using a proportional joystick positioned at his mouth.

Antre is maintained in an 90/90 seated upright position through the use of a thoraco-lumbar-sacral orthosis (TLSO), also known as a body jacket. A molded plastic head support attached to the body jacket using a piece of spring steel, maintains his head position. The head is held in the support by an anterior strap positioned across the forehead. Because of it's clover shape, it is known as a cloverleaf head support.

This positioning system, combined with scheduled pressure relief by way of the power recliner, provides Antre with a functional, upright seated posture. He can use a mouth stick, participate in adapted PE and interact with peers. In the summer of 1993, he began his power wheelchair driving training.

History of intervention

Antre has a history of skin breakdown on his head. He also has an asymmetrical neck muscle that forward flexed and rotated his head. The additional movement of driving the power wheelchair increased asymmetrical positioning, causing changes in his head position throughout the day. This made it difficult to properly position a joystick so that he could drive. The team next tried several versions of cloverleaf head supports to try to better control the head using three point contact (Figure 1).

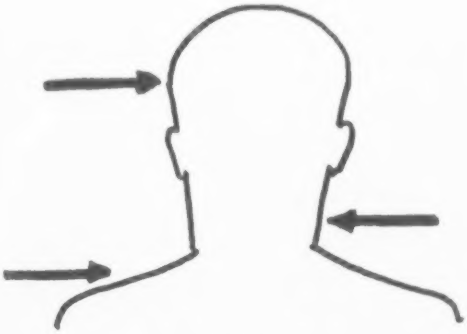


Figure 1

Custom Head Support

Between September 1993 and March 1994, Antre had a series of pressure sores on his head and neck. Many modifications to the body jacket head support were made in an attempt to relieve pressure on the affected areas. Head supports of different sizes, shapes and padding were tried. A larger cloverleaf head support was fabricated in an effort to distribute the pressure over a larger surface area. Foams of different densities were integrated in the head support to accommodate high pressure areas. Each modification to reduce pressure in one area increased pressure in another causing another pressure area in a different place. These interventions increased the frequency of skin breakdown on the head and neck.

Orthopaedic consult reported that the increase in difficulty in controlling Antre's head and the new pressure areas on his neck were due to the flexible scoliosis of his cervical spine. The orthopaedic recommendation was for surgical spinal stabilization, but due to outside factors, the surgery could not be scheduled until November, 1994.

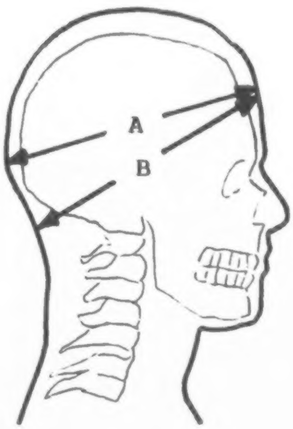
It was decided to try to identify an alternative solution to Antre's head positioning problem. The team consisting of members from physical therapy, orthotics and rehab engineering met to discuss options.

Method/Approach

What was needed was a way to control the head of a 7 year old child with C1-2 complete quadriplegia and a scoliosis of the cervical spine, without further damage to his skin. Evaluation showed that Antre's scoliosis was flexible and correctable with a minimal amount of traction.

The commercially available S.O.F.T. head rest, by Whitmyer Biomechanix, was investigated but could not be used because the support surfaces rested on tender scar tissue from previous pressure sores.

It was decided to implement a new design based on work done by individuals at the Sunny Hill Health Centre for Children (Cooper). The design operates on the premise of using a solid ring to provide anterior support to the forehead and posterior support to the occiput. Since the diameter of the head from the forehead to the back of the skull is larger than the diameter from forehead to occiput, the ring will not slip off (Figure 2). Such a system could hold the head and, if properly adjusted, provide some traction to the cervical spine.



Distance **A** is Greater Than Distance **B**

Figure 2

To reduce the probability of high pressure areas at the forehead and occiput, the design was further modified to distribute the force required to hold the head equally about the circumference of the ring. This was done with a custom Roho Adapter pad, used to line the inside of the head ring. The Adapter pad used is a single line of 18, 1" square, 3/4" high air cells, modified by the addition of an air valve to allow air to flow between cells. The theory of using air as a support surface is that air in cells under high

270

pressure areas will move to adjacent cells equalizing the pressure circumferentialy. The overall pressure applied to the head can then be adjusted using the valve.

Results

The head support developed was fabricated in two pieces. The posterior half of the ring was fabricated from 1/8" aluminum, while the anterior portion of the ring was fabricated from 1/16" Kydex. Both portions of the ring were contoured to approximately 1/2" of the shape of Antre's head. The posterior half of the ring was attached to the body jack using the standard head support attachment, and the Kydex anterior portion was loosely riveted to the aluminum on one side to allow it to rotate up and out of the way. This was necessary to get the body jacket on and off. The modified Roho pad was attached to the inside of the ring using velcro, and the valve was passed to the outside of the ring through a hole in the aluminum.

The jacket with the new head support was fitted and adjusted and a carefully monitored "break in" period was started. Nursing was trained on the care and use of the new head support, and instructed on how to put Antre into the system.

The head support was initially used for only 30 minutes the first day and its use increased in 15-30 minute intervals, as skin tolerance increased. Within three weeks Antre's sitting tolerance was 4 hours, twice a day, with an hour pressure relief in between. At the end of the 4 months of use he was sitting up to 14 hours per day in 4-6 hour blocks. Physician's orders limited Antre's time in the head support and required an hour of pressure relief every 4-6 hours. This was to ensure that Antre did not have any skin breakdown prior to his surgery.

Discussion

Staff felt that the new head support was successful. Maintaining position by slight traction of the cervical spine caused less high pressure areas as compared with three point control. Antre could sit in a functional position and drive his wheelchair without skin breakdown. Due to its lower profile, staff and peers preferred the cosmesis of the new support over the old supports. Antre's head positioning was greatly improved, although there was still some need for repositioning over the course of the day. The head rest did require more training of nursing and other support staff because it was new, had more moving pieces, and had to be more closely fit than what they were previously accustomed to.

Further refinement and adjustment may eliminate the need for the scheduled hour of pressure relief. Since Antre's therapists plan to continue use of the new head support after Antre's spinal fusion, anticipate an update by the time of publication.

References

Cooper, D., "Head control - we're not there yet." Presented at the 10th International Seating Symposium, Vancouver, BC, Canada, February, 1994. pp. 69-72.

Acknowledgements

The authors would like to thank Tom Borcherding and Roho for their assistance and the donation of the custom Adapter pad, and Stephanie Langdon for her support.

Kevin Caves
Rancho REC/CART
7601 E. Imperial Highway
Downey, CA, USA 90242
Phone: (310)940-6800
FAX: (310)803-8892

A Wheelchair Modification To Assist With Pressure Relief Performance in Low Level Quadriplegia

Chip Fiske
Sharon A. Mockett PT
Shepherd Spinal Center

ABSTRACT

Low level (C 5-7) quadriplegics can have difficulty performing independent pressure reliefs in power upright wheelchairs. A simple modification was designed to assist these individuals in performing this task.. This modification, the pressure relief lever, allowed these individuals to independently perform pressure reliefs. Therefore, they did not require a power recline/tilt system and they were able to choose a more aesthetically pleasing wheelchair that would not compromise their skin integrity.

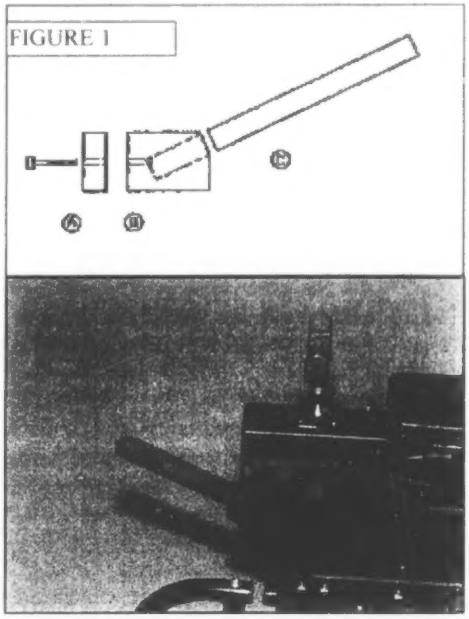
BACKGROUND

Selection of a wheelchair for a person with low level quadriplegia requires examination of many factors, including the ability to independently perform pressure relief maneuvers. The decision between a power upright and power recline/tilt wheelchair is often based upon this ability. With the drastic decrease in the length of stay for inpatient rehabililtation and the funding available for durable medical equipment, prescriptions for wheelchairs are often completed before the patient has reached his functional potential. There are also increased demands to make the wheelchair cost effective; there is a several thousand dollar difference between the power upright and recline/tilt wheelchair.

STATEMENT OF PROBLEM

Low level quadriplegics have demonstrated the ability to independently perform a forward leaning weight shift in a manual wheelchair using 6 inch brake extensions. The same individual could not perform this task in a power upright wheelchair; specifically they could not return to the upright sitting position. Evaluation of this task in the manual and power upright wheelchairs demonstrated that the individuals did not have a place for their hands in the power upright that was comparable to the brake extensions on the manual upright. A manual wheelchair was not appropriate as they could not push for extended distances or on uneven terrain. These individuals did not want a power recline/tilt wheelchair that could be accessed by an elbow toggle switch because of the visual appearance and the desire to use their limited musculature for this skill. A lightweight, durable, inexpensive and aesthetically pleasing pressure relief lever was designed for the power upright wheelchair to assist these individuals to independently perform pressure reliefs.

FIGURE 1



DESIGN/DEVELOPMENT

The pressure relief lever is composed of three major parts: (A) the proximal end cap with screws, (B) the main body and (C) the handle. (See figure 1) The end cap and the main body are composed of 2 inch diameter cylinder shaped Delrin AF plastic connected with 1 1/2 inch cap head screws. The end cap and the main body together are referred to as the bracket. The handle is composed of aluminum tubing, 9/16 inch inside diameter and 3/4 inch outside diameter, 7 inches in length. The handle is covered with black foam grip. The end cap and the main body are designed to clamp around the armrest of the wheelchair when the screws are in place. The distal end of the main body is partially cut a 25 degree angle from vertical with a 2 inch long and 3/4 inch wide hole into which the handle is placed. The bracket design allows vertical and rotational adjustment on the armrest in order to place the handle in the ideal location for the individual.

EVALUATION/DISCUSSION

Eight individuals with C 5-7 quadriplegia have utilized this lever on power upright wheelchairs to independently perform forward leaning pressure reliefs. Without this lever the seating team would have had three choices, none of which would have fully met the needs of the individuals: a power upright wheelchair in which the individual required assistance with pressure relief, a power recline/tilt system which is significantly more expensive and physically larger, or a manual wheelchair which they could not propel long distances or on uneven terrain. The material cost of the lever was approximately 20 dollars per pair. The lever allows low level quadriplegics to safely and independently perform pressure relief, increasing the likelihood that this habit would be continued upon discharge. The seating clinicians responsible for the final wheelchair prescription could feel confident that this skill was fully developed. To date there has been no report of equipment failure.

ACKNOWLEDGMENTS

Special thanks to the physical therapy and assistive technology staff at Shepherd Spinal Center.

ADDRESS

Shepherd Spinal Center
2020 Peachtree Rd.
Atlanta, GA 30309

EVALUATION OF A POWERED WHEELCHAIR EVALUATOR

Nanette S. Hughlett, M.E.
University of Virginia, Rehabilitation Engineering Services
Charlottesville, VA

ABSTRACT

Powered wheelchair evaluators, such as the Turtle Trainer by Bressler (1), have been designed to assist in the evaluation and training of individuals with limited physical abilities while in their own seating system. Although these devices have been found to perform like a powered wheelchair(2), they have never been tested on individuals with complex seating systems. This study tested individual's with their own seating and found that they performed the same in a powered wheelchair as they did in a powered wheelchair evaluator. Therefore, powered wheelchair evaluators provide the rehabilitation team a tool for evaluation and training of multiple users in a timely and efficient manner.

BACKGROUND

Self-produced mobility has been found to be very beneficial to individuals. It provides a sense of independence as well as allowing the individual to attain a certain level of perceptual and cognitive skills (3,4). For individuals with extremely limited physical abilities a powered wheelchair (PC) may be able to provide this mobility. Due to the high cost of a PC and seating, it is important to determine that the individual is able to control the wheelchair safely before the investment is made. The first step in any powered wheelchair evaluation is to have the individual properly seated. Next, the functional movements of the individual can be assessed. Assessment and training for powered mobility can take place by performing simulated activities using a joystick or switch to control a toy or a computer. Computer simulation provides some information to the rehabilitation team, but positive results on a computer simulator do not guarantee performance on a PC. The computer simulator does not provide the sensory feedback or inertia that takes place as movement occurs (5,6). Although computer simulation may provide some early training, it is crucial that an individual be tested in a PC in their seating before any final decisions are made.

To better facilitate powered wheelchair evaluation and training, powered wheelchair evaluators (PWE) have been designed. These devices were designed to aid in the evaluation and training of individuals with physical disabilities that put them on the edge between dependant and independent mobility. The PWE's are motorized platforms to which an individual's manual wheelchair can be mounted and fastened allowing evaluation in one's own seating system(1).

Although some differences exist between PWE's and PC's, Schmeler found in testing the Powered Wheelchair Mobility Simulator (PWMS), that for experienced power wheelchair users "the PWMS performs within the realm of an actual powered wheelchair and could be considered a viable tool for the assessment and training of powered mobility readiness"(2).

RESEARCH QUESTION

The purpose of this project was twofold. First, was to determine if control of a PWE is the same as the control of a PC. Secondly, this project will determine if an individual with their own seating system performs differently during a powered wheelchair evaluation when controlling a PWE than when controlling a PC.

METHODS

Subjects: Eight able-bodied individuals with little or no powered wheelchair experience volunteered to participate in this study. Five disabled wheelchair users were tested, all were diagnosed with Cerebral Palsy.

Apparatus: The PWE used for this project was designed at our facility. The Power Evaluator Trainer (PET) was fabricated by mounting an Invacare Arrow XT power base to a plywood platform with the two motorized wheels in the back and a swivel mount caster in the front center of the platform. The controller is an Arrow MKII, which is compatible with virtually any joystick or switch. A nylon strapping system is located on the platform providing a cam locking system at four locations. This allows the user's wheelchair to be mounted on the evaluator. The PET has a controller which allows multiple access methods to be used. Proper positioning of the control devices can be attained by using the two universal mounting systems on the

PET.

The PC used for comparison to the PET was an Arrow XT with a MKIII controller. The MKIII controller of the PC and the MKII controller of the PET were able to be identically set during the testing. The able-bodied individuals were tested using the standard proportional joystick controlled by their dominant hand. For the disabled individuals, control was determined according to their functional abilities and set up the same for both mobility devices. The different setups used included head switches, foot switches, a joystick with a T-handle, and switches placed on a tray. For testing the disabled individuals in the powered wheelchair, the seating was set up, to the extent possible, to match their normal seating system.

The Course: The course for this study was set up in a gym, and was outlined in blue masking tape on the floor. The course consisted of five straight pathways, two forty five degree turns, and three ninety degree turns. This is the same course used by Lefkowicz (6) and Schmeler (2).

Testing Procedure: Each subject drove both the PC and the PET. Half of the subjects started in each mobility device. While each subject was being set up, the time was recorded. This time included providing seating in the PC, tying down the manual wheelchair to the PET, and setting up the access device for controlling the mobility device. Once the subjects were seated properly and the control system was set up, they were given some time to practice. The normal subjects practiced for about 5 minutes. The disabled subjects, were given about half an hour of practice to assure their understanding. The subjects were taken to the course and asked to drive around the course staying as close to the middle as possible. They were told to drive and take the corners however they felt comfortable while maintaining consistency. The subjects drove the course two times in each direction while being timed. Their path was marked on the course with a marker attached at the midpoint of each device. The procedure was repeated for both mobility devices.

Once the testing of subjects was completed, the data was collected. For each trial, the perpendicular deviation from the midline was measured every six inches, to the nearest eighth of an inch. Measurements were taken from 18 inches after to 18 inches before each turn. The measurement within the turn was not recorded as each subject had their own style of maneuvering the corners(2). These measurements were used to calculate the average squared deviation, maximum deviation, average location before and after a turn, and the range travelled around the midline.

To determine if the PET acted like a PC the normal subject performance measures were analyzed. To determine the effect of performance in their own seating system, the measures of the disabled individuals were analyzed. Each performance measure was analyzed between each device for each subject group using the Friedman Nonparametric test with a 0.05 level of significance.

RESULTS

The results for the able-bodied and disabled individuals are presented in Table 1. The significant variables for the able-bodied subjects found the range travelled in the PET was larger than the range of the PC, just as the maximum deviation was greater for the PET. In driving the course, the PET had a slower course time than the PC. For the disabled subjects, the only significant difference was that the PET took less time to set-up before testing.

DISCUSSION

The three instances that showed significant differences between the PET and PC were expected due to the design of the PET. The PET has a longer wheelbase and the manual wheelchair is placed in front of the drive wheels. These differences can account for the larger range and maximum deviation when driving the PET. The fact that the PET was slower can be explained due to the added weight of the PET's platform. Yet, the PET performed the same in the straight sections and the turns. Therefore, for evaluation and training the PET performs well and could be used instead of a PC for evaluation. This is in agreement with the results found by Schmeler(2).

For the disabled subjects, the only significant difference between the PET and the PC was the set-up time. It took half the time to set up the disabled individual in the PET because no seating needed to be mocked-up. This allows more time to be spent by the clinician evaluating the individuals driving instead of arranging their seating. Also, the reduced set up time decreases the fatigue of the disabled individual allowing more time to practice driving. Finally, a reduction in time is more cost effective to all concerned. The disabled subjects did not seem as affected by the size or weight of the PET. This could be because their movement of the joystick and switches used for interfacing the controller are not as steady as the able-bodied individuals due to athetoid or spastic movement caused by their Cerebral Palsy. Therefore, there were no significant differences in the driving performance measurements between the PET and the PC. These results show that the PET is a very viable option for the evaluation and training of the disabled for powered mobility.

CONCLUSION

Powered Wheelchair Evaluators,-such as the PET are valuable training and evaluation tools for individuals on the boarder between dependent and independent mobility. In the testing of individuals with their own seating system the set up time is halved. This allows clinicians to spend their time thoroughly evaluating the clients control of driving. By using their own seating systems, their performance should be at their best. PWE's provide several mounting locations to allow the controller to be effectively placed for evaluation. A final benefit of powered evaluators is their versatility. They can easily be used by several individuals in a short time as no permanent changes are made to the evaluator's base to allow use by each subject.

REFERENCES

1. Bressler MI. Turtle Trainer: A way to evaluate power mobility readiness. In: *Proceedings of the 13th Annual RESNA Conference*. Washington, DC: 1990; 399-400.

2. Schmeler MR. Performance Validation of a Powered Wheelchair Mobility Simulator. Unpublished Master's Thesis, SUNY at Buffalo, Buffalo, NY: 1993.

3. Taplin CS. Powered Wheelchair Control, Assessment, and Training. In: *Proceedings of the 12th Annual RESNA Conference*. New Orleans, LA: 1989; 45-46.

4. Tefft D, Furumasu J, Guerette P. Cognitive Predictors of Successful Powered Wheelchair Control in the Very Young Child. In: *Proceedings of the 15th Annual RESNA Conference* Toronto, Ontario, Canada: 1992; 412-414.

5. Widman LM, Cooper RA, Robertson RN, Ster JF, Grey TL. Evaluation of an Isometric Joystick For Power Wheelchair Control. In: *Proceedings of the 16th Annual RESNA Conference*. Las Vegas, NV: 1993; 364-366.

6. Lefkowicz AT, Wierwille WW. Validation of a PC-Based Perspective-View Wheelchair Simulator. In: *Proceedings of the 15th Annual RESNA Conference*. Toronto, Ontario, Canada: 1992; 415-417.

Nanette S. Hughlett
Rehabilitation Engineering Services
Box 35-BRH
Charlottesville, VA 22908
(804) 982-3845
e-mail njs8j@virginia.edu

Table 1 - Performance Results

	Performance Results - Able-Bodied			Performance Results - Disabled		
	PET	PC	Stat	PET	PC	Stat
Average Squared Deviation	33.89 ± 9.99 in	27.72 ± 12.83 in	NS	280.84 ± 75.34 in	262.66 ± 158.15 in	NS
Position Before Turn	3.49 ± 1.48 in	1.69 ± 2.14 in	NS	48.48 ± 7.22 in	42.26 ± 11.24 in	NS
Position After Turn	6.53 ± 1.89 in	4.65 ± 1.69 in	NS	9.20 ± 2.75 in	5.02 ± 2.55 in	NS
Range	19.40 ± 2.54 in	14.95 ± 2.81 in	p=0.034	9.90 ± 3.41 in	6.06 ± 4.52 in	NS
Maximum Deviation	10.75 ± 3.69 in	5.93 ± 4.01 in	p=0.034	28.86 ± 9.31 in	15.56 ± 13.85 in	NS
Course Time	42.98 ± 4.39 sec	30.79 ± 3.11 sec	p=0.005	128.72 ± 57.65 sec	126.68 ± 52.58 sec	NS
Set Up Time	186.33 ± 47.42 sec	300.00 ± 97.07 sec	NS	481.20 ± 234.42 sec	920.40 ± 135.08 sec	p=0.025

BEST COPY AVAILABLE

Tracking System for Seating and Wheeled Mobility Equipment in a Rehabilitation Center

Marcia K. Margolis, P.T. , University of Minnesota Hospital and Clinics, Minneapolis, MN
Linda Lorentzen, O.T.R., University of Minnesota Hospital and Clinics, Minneapolis, MN
Lou Burbach, P.T.A., University of Wisconsin Hospital and Clinics, Madison, WI

Abstract

This paper describes the utilization of an inventory/tracking system used successfully in two major university rehabilitation center settings The system was developed by a rehabilitation equipment coordinator (physical therapist assistant) and the physical therapy rehabilitation supervisor.

The system tracks the distribution, and facilitates retrieval/return of seating and wheeled mobility equipment owned by, or loaned to, the rehabilitation center. It has proved effective in both in-patient and outpatient applications.

The system is currently in use by physical therapy and occupational therapy departments.

Background

The rationale that precipitated the development of this tracking system was two-fold; one a clinical benefit to the client/consumer and one a financial benefit to the institution and to the manufacturers loaning equipment to the rehabilitation center.

As more trial samples of new equipment designs became available to the rehabilitation center and to the consumer/client, the problem of regulating and documenting the clinical use of these samples multiplied. Many hours of the clinical team's, and the client/consumer's, time was wasted through repetitive trials with the same or virtually identical seating components, cushions or wheeled mobility systems.

	Date	Therapist	Patient/Rm	Accessories
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
JC01 #101 16 x 16 Jay Cushion				

Example of Inventory/Tracking Card

The equipment available for trial in most rehabilitation centers comes from two sources. Either it is purchased by the institution, specifically for evaluation trials by the client/ consumers, or it is loaned to the institution by the manufacturers.

In a setting where many therapists had access to, and chose to actively make use of this evaluation equipment, problems arose with tracking and retrieval of loaned equipment. Many thousands of dollars of the institution's and manufacturer's money was lost. Equipment was not returned, ended up on other units within the hospital or was put to use for other clients/consumers. This last issue has a particularly deleterious clinical effect. The equipment often found its way to another user without inspection, repair or cleaning.

Objectives

The objectives for developing the tracking system were to:

- provide the client/consumer and the seating team with a means of documenting the types of equipment, and duration of trials, before recommending and ordering definitive equipment;
- help assure the return of loaned equipment and prevent financial loss by the institution and the manufacturers;
- assure that "loaner" equipment is available for trials by subsequent client/consumers;
- provide ongoing documentation of the use of different types of trial equipment;
- assure that all equipment was inspected, repaired and cleaned between trials by different client/consumers;
- make the system simple, take less of the therapist's time, and be easily learned by new staff ; and
- be administered by either a therapist or a therapist assistant.

Methods

The existing stock of equipment was inventoried and divided by manufacturer, and then subdivided by manufacturer's product number. Each piece was assigned (and labeled) a code number. For example: a Jay cushion was assigned an internal code number, e.g., JC01. Each successive Jay cushion was labeled in a similar manner, i.e., code JC02, JC03, etc. Though this did not supply a unique identifier of the particular cushion type, it allowed for a very simple numbering and inventory system. A more detailed description of the product was included on the Inventory Tracking Card attached to the product box, while a complete description, including hardware and other pieces, was kept in a Cardex™ file.

The Cardex™ file is the master inventory list for the equipment owned by, and loaned to the department. When a particular piece of equipment in removed for client/consumer trial, the Inventory Tracking Card is filled out and placed in the Cardex™ file. At a glance, the equipment coordinator can tell what equipment is available.

When the client/consumer is finished with the equipment, it is returned to a "dirty" area. It is then inspected, cleaned and/or repaired and returned to inventory. The Inventory Tracking Card is removed from the Cardex™ file, the last name is crossed off, and returned to the plastic pocket on the product box.

Conclusion

Trial equipment helps to assure that appropriate technology is supplied for the client/consumer. Educated choices can be made only when the diversity of existing product is explored. Keeping track of "loner" equipment is a formidable challenge. The system presented in this paper is one that has proven successful in two diverse university rehabilitation centers.

Marcia K. Margolis, P.T.
Rehabilitation Services
University of Minnesota Hospital and Clinics
Box 106
420 Delaware Street
Minneapolis, MN 55455

Standardization of Electrical Loads Imparted on Powered Wheelchair Drive Systems by Double Drum Test Machines

William D. Evans, MS and Louis Molino, MSME
Department of Veterans Affairs - Rehabilitation Research and Development Service
Baltimore, Maryland 21202

ABSTRACT

Part 8 of the ANSI/RESNA Wheelchair Standards(1) requires that powered wheelchairs be fatigue tested on a double drum test machine. During this test, the drive motor on the double drum test machine is disengaged and the wheelchair is required to provide the driving force to rotate the drums. Therefore, Part 8 examines both the integrity of the wheelchair's electrically operated drive system as well as the strength of the wheelchair's structure. The objective of this project was to investigate possible inconsistencies in results when identical wheelchairs are tested on different double drum test machines and to develop a methodology, using existing test apparatus, that will minimize any test result variations. This project revealed that inconsistencies existed in these electrical loads and developed a new test method which reduces variations. Further work in developing and publishing techniques relative to the implementation of ANSI/RESNA Wheelchair Standards would be beneficial in promoting repeatability between test sites.

INTRODUCTION

ANSI/RESNA WC/08 1991 requires that wheelchairs be fatigue tested on a double drum test machine (figure 2). In the case of powered wheelchairs, the test machine drive motor is disengaged and the wheelchair drive system provides the force required to rotate the drums. Thus, the fatigue test examines both the integrity of the wheelchair's electrically operated drive system under load as well as the strength of the wheelchair's structure. Normally, the loaded wheelchair would simply be placed on the double drum test machine and adjusted to a forward speed of 1 m/s ±5%. As the configuration and mechanical condition of double drum test machines vary from one test lab to the next, so may the test results. The electrical drive system of identical wheelchairs may complete many more cycles without failure on a double drum test machine whose drum-rolling resistance is small verses a double drum test machine whose drum-rolling resistance is large. It is important that results between test sites be accurate and consistent so that prescribers and end-users can make intelligent comparisons and procurement decisions.

Double Drum Test Machine No. 1

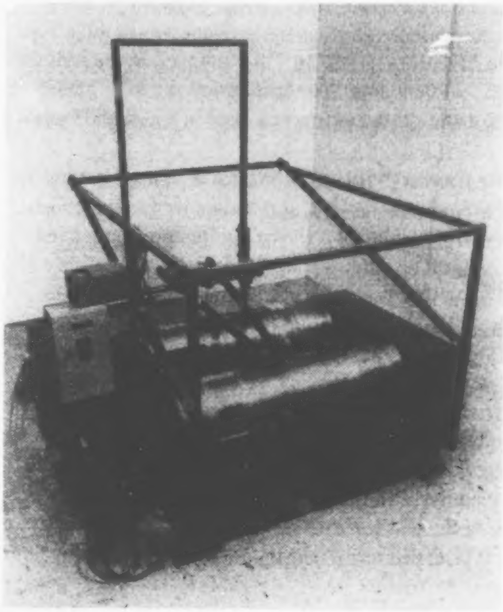


Figure 2

METHOD

The current-draw of two wheelchairs (A and B) was measured while the wheelchairs were moving forward on a smooth, flat, horizontal surface, on double drum test machine No.1 (figure 2), and on double drum test machine No.2 (not shown). In each case, the wheelchairs were loaded with a 100 Kg ISO dummy and adjusted to maintain a speed of 1 m/s ±5%. The double drum test machines had their slats removed and drive motors disengaged and the powered wheelchair drive systems were allowed to provide the force necessary to rotate the drums. Current-draw was measured at the battery and due to the complexity of the current wave-forms (figure 3), each current draw value obtained represents the mean of ten 0.5 second samples of current at a 200 Hz sample rate (1010 data points). The mean, current-draw value for each test configuration was

279

examined, compared, and variations noted. The existence of variations prompted the development of a new test method which attempted to standardize the current-draw on various double drum test machines and bring it closer to the value present during normal use (level ground).

The new test method permits the current-draw of a powered wheelchair on a double drum test machine to be adjusted to the value which exists when the wheelchair is moving forward on level ground. This not only allows the wheelchair to be tested under conditions similar to normal use, but comes close to standardizing the electrical loads imparted by double drum test machines of various designs and mechanical conditions.

The following procedure was utilized to accomplish this goal. Wheelchair speeds and loading remained at 1 m/s ±5% and 100 Kg respectively.

1) Measure the current draw of the wheelchair while traveling forward on a smooth, flat, horizontal surface. Make arrangements for the joystick and/or speed adjustment potentiometer to be placed and fixed in this position during a later step (figure 4).
2) Place the wheelchair (drive system disengaged) on the double drum test machine (drive motor engaged and slats removed).
3) Start the double drum test machine and adjust the drum rotation to a frequency which coincides to a forward wheelchair speed of 1 m/s ±5%.
4) Adjust and fix the wheelchair speed control device to the previous level ground adjustment (1 m/s ±5%, step 1).
5) Engage the wheelchair drive system and monitor the current.
6) If the wheelchair wants to move slower than the drums, the current will be in a direction that will charge the batteries. If the wheelchair wants to move faster than the drums, the current will be in a direction that will discharge the batteries.
7) Fine tune the wheelchair speed using the speed potentiometer or joystick fixture until a discharge current exists which is equal to that measured on level ground.
8) Verify that there is no slippage between the drive wheels of the wheelchair and the respective drum tester drum.
9) Mark both the wheelchair and double drum test machine controls so that the settings can be duplicated - then turn off both devices.
10) Install the slats on the double drum test machine, start up the wheelchair and tester in the same fashion as before, and adjust both the wheelchair and double drum test machine to the previously marked settings which coincide with the level ground current-draw value (step 9).

The current-draw of the wheelchair under test will be approximately equal to the value that exists with the wheelchair moving forward on level ground plus the additional current required to traverse the drum slats.

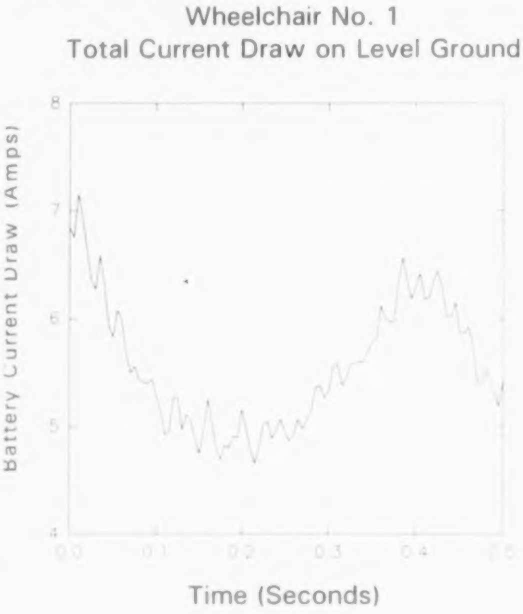


Figure 3

Joystick Deflection and Control Fixture

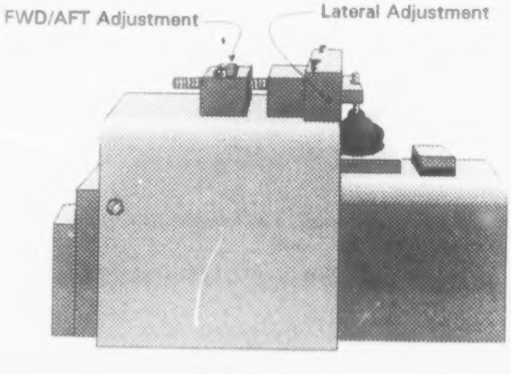


Figure 4

RESULTS

Wheelchairs A and B were tested on both double drum test machines and on level ground to investigate the possibly of inconsistencies between the three test configurations. Wheelchair A was subjected to the new test method on double drum test machine No.1 in order to demonstrate that the electrical load could be adjusted to the desired level ground value. Table 1 is a summary of the results.

	W/C A Amps	W/C B Amps
1).Level Ground	3.94 ±.44	5.42 ±.60
2).Drum Tester No.1	6.56 ±.69	6.96 ±.82
3). Drum Tester No.2	8.40 ±.44	8.55 ±.46
4).Drum Tester No.1 New Test Method	4.07 ±.57	

Table 1

A students t-test of the data sets represented by 1 and 4 of wheelchair A (table 1) showed a significant difference in the current-draw at $p < .05$

DISCUSSION

Performance of the double drum fatigue test in accordance with the existing test method yielded variations between level ground current-draw and double drum test machine current-draw of 28.4% to 113.2%. There was as much as 28% difference between the electrical loads offered by double drum testers No.1 and No.2 for the same wheelchair. Implementing the new test method allowed the current-draw of the wheelchair to be adjusted to the level ground value within +3.3%. This adjustment will also enable the current-draw values between double drum test machines of varied design and mechanical condition to be approximately the same. The students t-test of the two sets of data (represented by 1 and 4 of wheelchair A, Table 1) indicated they were not the same ($p < .05$). This may be due to the erratic nature of the current-draw wave-form. The small difference in the average values of current-draw would seem to indicate the wheelchair drive system was loaded similarly during both level ground and drum test measurements. The new test method not only comes closer to standardizing electrical loads during the fatigue test using existing test machines, but it allows wheelchair drive systems to be tested with electrical loads similar to normal use (level ground).

CONCLUSION

The results of this project indicate that electrical loads imparted on powered wheelchair drive systems, by various double drum test machines, vary depending on the design and mechanical condition of the particular double drum test machine on which the wheelchair is tested. It also indicates that the average current-draw experienced by the wheelchair drive system, while providing the force required to rotate the drums of the double drum test machine, is significantly higher than that experienced when the wheelchair is moving forward on level ground. This situation could cause a particular wheelchair's drive system to perform more cycles without failure on one double drum test machine than on another depending on the differences in electrical loads imparted. It could also cause a drive system to fail prematurely due to abnormally high electrical loads. The new test method comes close to standardizing the wheelchair electrical loads between drum testers and thus, between test sites. It also approximates the electrical load that exists while the wheelchair is moving on level ground (normal use). It is realized that additional testing with a larger wheelchair population may be necessary to further validate and improve the new test method. Further work in developing and publishing techniques relative to implementation of the ANSI/RESNA Wheelchair Standards would be beneficial in promoting repeatability between test sites.

REFERENCES

ANSI/RESNA Wheelchair Standards
WC/08 1991 Static, Impact, and Fatigue Strength Tests

ACKNOWLEDGEMENTS

Rehabilitation Technology Assessment Section
Rehabilitation Research and Development Service
Department of Veterans Affairs

William D. Evans
Biomedical Engineer
Technology Transfer Section
Rehab R&D Service
Dept. of Veterans Affairs
103 South Gay Street
Baltimore, MD 21202
(410) 962-2133

EVALUATION OF A LASER DISPLACEMENT SENSOR FOR USE IN SPECIAL SEATING

Dominic P.K. Cheng
Rehabilitation Engineering Centre
Hong Kong Polytechnic University, Hong Kong

ABSTRACT

Commercial shape-sensing equipment for special seating uses displacement sensors that require direct contact with the surface it measures. This paper evaluates a relatively low-cost laser displacement sensor with a measurement range of 300±100mm for suitability in measuring the contour impressed on a rubber moulding bag. Results indicate that except for unusually severe contours, the sensor is most likely suitable for this application.

BACKGROUND

At present, there are three commercial products available for shape sensing in special seating. The first product measures the contour of the end-user directly. It relies on displacement of an array of sensors embedded in a piece of foam on which the end-user sits. The amount of displacement of each sensor is mechanically encoded and imprinted on a multi-part form. The other two products measure the surface of a moulding bag impressed with the contour of the end-user. One product uses a row of linear displacement sensors in the form of an 'electronic carpenter's scale'. The row of sensors is manually moved across the moulding bag and displacement data are captured with a PC based data-acquisition system. The third product incorporates a 3-D magnetic tracking device with co-ordinates referred to the tip of a stylus. A seating specialist traces a moulding bag with the stylus by repeatedly pointing and clicking (as if using a '3-D mouse') to capture the impressed shape with a PC-based data-acquisition system.

All the above products rely on contact sensing. The implication is that to capture contours at close enough spacing, either a large array of sensors is required or a single sensor has to be moved to different measurement points. Moving and positioning a sensor manually can be done intelligently, such as collecting more data for sharper contours , but this requires expert know-how. Moving and positioning a sensor automatically is possible but it takes much longer because an 'avoidance scheme' has to be implemented to overcome sharper contours (1). For automatic tracing of a moulding bag rapidly, a non-contact sensing technique is required.

The author found a relatively low-cost laser displacement sensor from Keyence Corp (Keyence Corporation, 2-13 Aketa-cho, Takatsuki, Osaka 569, Japan.) which has a long measurement range and is purported to be popular with tire manufacturers. Brief specifications of the Keyence LB301/LB1201 sensor are as follows:

Reference distance	300 mm
Measuring range	±100mm
Linearity	0.4% of F.S
Light spot size	1.2x2.5mm (at 300mm)
Output	±5V (20mm/V)

With this wide measurement range and small light sport size, it is most suitable for shape sensing in special seating.

OBJECTIVES

The author intends to use the above non-contact displacement sensor for automatic tracing of a moulding bag if satisfactory answers are obtained for the following questions:

1. Commercial moulding bags come in a range of colours. Is the LB301/LB1201 sensor sensitive to colour?
2. Can the sensor measure a moving curved surface with acceptable accuracy?

METHOD

The LB301 sensor head was mounted on the Z-axis of a vertical machining centre and was aligned so that the laser beam was vertical to the table of the machine. The targets were put on the table using a holding jig if required (Fig.1). The co-ordinates of the machine are X (right-left), Y(back-front) and Z(up-down).

A. Colour sensitivity test

Five different small targets were placed on a parallel bar. Gummed labels were used to space the targets so that they were approximately at the same height. Each target is moved manually under the beam to its own X-Y co-ordinate and sensor output was taken manually using the digital multi-meter at every 10mm of vertical displacement (Fig.2).

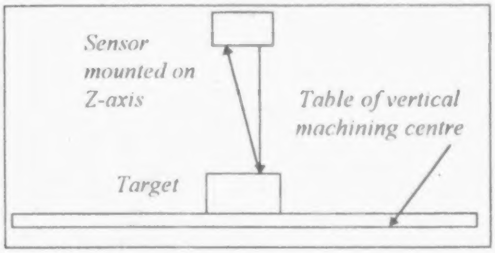


Fig. 1 Mechanical set-up

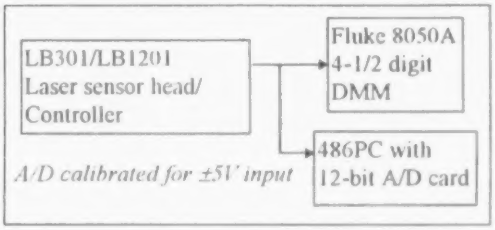

LB301/LB1201 Laser sensor head/ Controller
Fluke 8050A 4-1/2 digit DMM
486PC with 12-bit A/D card
A/D calibrated for ±5V input

Fig.2 Block diagram of equipment for data acquisition

B. Calibration using a black rubber target

After the colour sensitivity test, the sensor was calibrated using the black rubber target used in Part A. The target remained stationary but the sensor was moved at a rate of 20mm/sec while the PC was collecting data at 10sample/sec.

C. Measuring known contours

A black rubber basket ball with imprinted colour graphics was placed on the table. The highest point was found by moving the ball in the X-Y plane for a maximum height reading using the digital multi-meter. A program written for the machining centre moves the table at a convenient feed-rate to travel a distance exceeding the diameter of the ball. Since there is no synchronisation of PC data collection to table movement, data collection was started before the table was made to move. Data were taken at a feed-rate of 2mm/sec and 10 sample/sec.

This procedure was repeated with a mat blue rubber ball with a diameter of 56.8mm.

RESULTS

A. Colour sensitivity test (Fig.3, Table 1)

The sensor is linear with all the five different targets. Since the slopes are almost identical and the small differences in intercept can be accounted for as a result of unequal height of the targets, the sensor is not obviously sensitive to the different colour, finish or material of the targets.

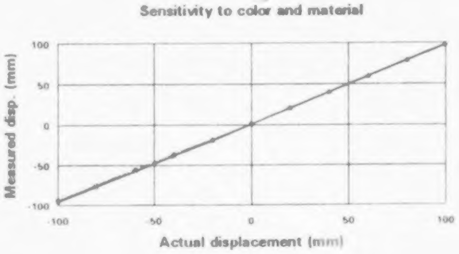


Fig. 3 Displacement measurement using 5 different targets

	Mat white paper	Black rubber	Grey PVC	Mat green plastic	Mat yellow plastic
slope	0.97	0.96	0.97	0.97	0.98
intercept	0.46	1.73	0.58	1.80	0.64

Table 1 Least square fit lines of data from Fig. 3

B. Calibration using a black rubber target (Fig. 4)

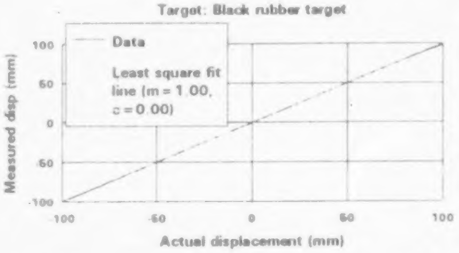


Fig. 4 Calibration of sensor using a black rubber target

The sensor is linear within its measurement range. There is a slight drop-off for the last 20mm of largest separation between sensor and target. The drop-off increased monotonically from 0 to 2mm. It was observed that the signal was a bit noisy in this region for black rubber but quite stable for mat white paper.

C. Measuring known contours

Fig. 5 indicates close correspondence between the measured values and a circular arc with the same presumed diameter. Fig. 6 shows that the measured values fall within ±2.5mm of predicted value starting from the apex down to a measured displacement of 10mm. A lower value of displacement corresponds to increasing approach towards the edge of the ball. Below a displacement of 0mm, a sharp drop-off occurs and the sensor can no longer track displacement.

Using a displacement of 10mm, the subtended angles is found to be close to ±75° from the vertical. In other words, assuming the basket ball is a sphere, the sensor can measure an arc ±75° with reference to its apex with an accuracy within ±2.5mm. It must be noted that the basket ball has 'regular pimples' on its surface to increase grip.

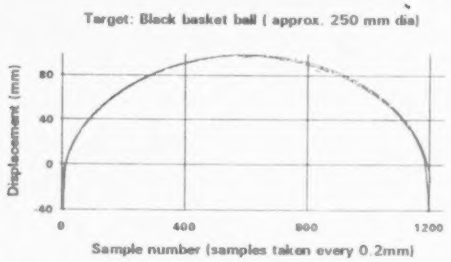


Fig.5 Data from the rubber ball superimposed with an arc with a radius of 124mm

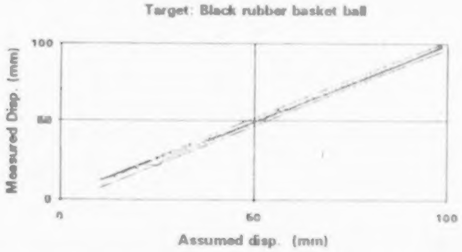


Fig.6 Measured displacement bounded by least square fit lines offset by ±2.5 mm

For the blue rubber ball, the measured values falls within ±0.5mm of predicted values from its apex down to a displacement of 65mm assuming its perimeter is a circle (Fig. 7). This range corresponds to a subtended angle of ±71° from the apex.

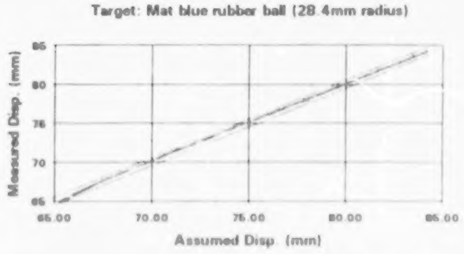


Fig. 7 Measured height bounded by least square fit lines offset by ±0.5 mm

DISCUSSION

The results indicate that the sensor can measure contours of moving spherical objects ranging from the surface of a black rubber basket ball to the small blue rubber ball with reasonable accuracy. With its insensitivity to the range of target colour/finish/material tested, it is reasonable to assume that it is suitable for shape sensing of a moulding bag in special seating.

The measurements done are by no means complete. No concave surfaces and no real moulding bags were measured. The dynamic response characteristics were not tested to the limit. Further measurements are required to better define its limitations and evaluation of the sensor in real situations are necessary to confirm its suitability.

REFERENCES

1. Cheng, Dominic (1994) A tracing head/barrier avoidance scheme for a 3-axis automatic shape sensing machine for special seating, RESNA'94, 304-5.

ACKNOWLEDGEMENTS

The author thank David Boone, Prosthetics Research Study, Seattle, Washington and Sam Echikawa, Keyence Corporation, Japan for supplying information on the Keyence laser sensors.

This work was supported by the Hong Kong Polytechnic

Dominic P.K. Cheng
REC, Hong Kong Polytechnic Univ.
Hung Hom, Kln., Hong Kong
Email: RCDPKC@HKPUCC.PolyU.EDU.HK

BEST COPY AVAILABLE

THE SOTO WHEELCHAIR

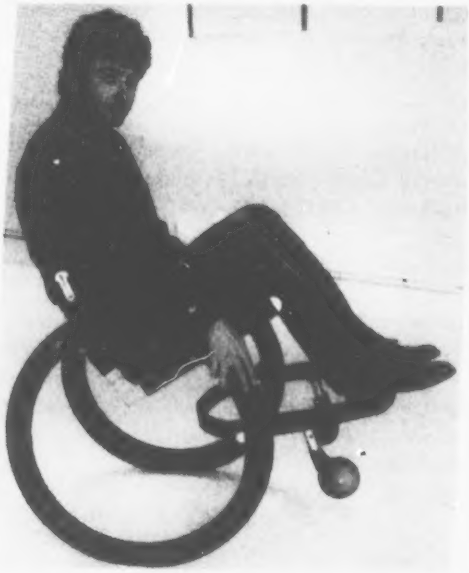
Pierre Soto, Montpellier France, Soto Works, Inc. Knoxville, TN
Sal J. Sheredos, Rehabilitation Engineer, Program Manager, Tech Transfer, Rehab R&D Service
Department of Veterans Affairs

ABSTRACT

The ideal of a wheelchair that renders inconspicuous the user's disability has taken a significant step closer with the SOTO wheelchair. This unique hub-less design offer great potential as it moves from development to the commercial market. The Department of Veterans Affairs, Rehab R&D is facilitating the transfer of this technology through various evaluation phases to validate and help define its commercial viability and production design.

BACKGROUND

Since its conception, the manual wheelchair (w/c) has undergone a continuous evolution. More efficient designs, new lightweight materials, and human factors considerations have made the wheelchair industry very competitive, and have produced many products of merit. Manual wheelchairs have developed into several classes which include: standard/everyday; lightweight; sport; racing; specialty; and institutional use chairs.



Pierre Soto, Montpellier, France conceived of a wheelchair that would be pleasing to the eye, yet reduce components; maintenance and repair; energy expended to propel; and, minimize stowage requirements. Based upon personal experience, he developed, built and used the first "SOTO" wheelchair.

"I have been using a wheelchair since I was injured in a motor bike accident several years ago. Having to use a chair made me realize that maneuverability, light weight and convenience were absolutely essential to my comfort. Moreover, I quickly found that a wheelchair must be reliable, very practical, and for me since I am a designer and an architect, possessed of desirable aesthetics.

By practical, I mean a chair I can use in all the situations of my life -- in my office, my home, or when I travel by car, by bus, plane, train, etc.

The wheelchair's maneuverability should be such that even a severely disabled person would find my chair easy to use and move about in.

A chair's appearance -- its aesthetics and the impact it has on those who see it -- is for me most important. My goal here, if you will, has been to make a chair so attractive that all who see it -- whether they are disabled or not -- will want to try it out or sit in it.

In short, I sought to move beyond the somewhat negative "medical" image so often associated with the wheelchair and replace it with a positive and entirely acceptable new perception -- in much the same way that contact lenses have replaced eyeglasses. This, in essence, is what led me to create the Soto wheelchair."

STATEMENT OF PROBLEM

Most manual wheelchairs either fold or disassemble for transport and stowage. The volume occupied by the w/c for storage is crucial in today's travel environment. Available space within automobiles is decreasing and wheelchairs are increasingly transported on airplanes, trains, and buses. Together with volume and the storage/transportation issue comes weight. In order to facilitate easy transport, the weight of the manual w/c must be kept at a minimum. The average weight of a lightweight manual w/c is approximately 19.3 lbs. Any disassembly of the w/c for storage and/or transport should not require the use of tools. Reducing components that make up the w/c will lead to reduced maintenance, repair, and weight. The lighter weight should contribute to lower energy requirements in propelling the w/c throughout the day.

DESIGN AND DEVELOPMENT

Soto Works Inc., is attempting to promote further evolution of the manual wheelchair by introducing commercially a new frame and wheel configuration based on Soto's development. The wheels, which utilize a unique hub-less design, not only carry the wheelchair but provide a portion of the frame geometry. It incorporates two large drive/carrying wheels mounted on opposite sides of a central frame. One portion of the central frame is collapsible and is designated to support a seat. Another portion of the central frame defines a footrest which also supports the swivel caster wheels. Each carrying wheel includes an outer ring and an inner ring. The outer and inner rings are concentrically oriented to each other such that the periphery of the inner ring and the inner periphery of the outer ring engage bearing elements located between them. The outer periphery of the outer ring is adapted to support a tire. The volume defined by the inner ring is devoid of any axle, shaft, or spoke. The frame is attached to the inner ring of the adjacent carrying wheels by releasable connectors. The wheelchair is designed to be folded or disassembled and stowed in a 26 inch (65 cm) diameter by 5 inch (12 cm) wide carry bag. This feature allows the device to be easily stored behind the drivers seat or in the trunk of an automobile or the cabin of public transportation.

Using a minimum of frame and wheel components allows the Soto wheelchair to further minimize the stowage and weight (low teens) requirements of more conventional designs. As with most products used today, esthetics and ease of use play a major role in its functionality and acceptance. The innovative and unique design of the Soto wheelchair together with its potential friendliness relative to human factors has placed it on the leading edge of wheelchair designs.

EVALUATION

The Rehabilitation Research and Development Service, Technology Transfer Section (TTS) administers a program to validate the safety, reliability and effectiveness of emerging products and techniques primarily developed with VA funding. These products and techniques are intended to optimize the rehabilitation of physically disabled veterans. TTS facilitates and promotes the clinical application and commercial availability of the successfully evaluated products.

Emerging products, not from within the Rehab R&D funded projects, are screened to identify those that the VA has an interest and need. TTS coordinates the manufacture and purchase of precommercial models for evaluation to determine if, and to what degree the development (product or technique) helps veterans to overcome in a safe and effective way, disabilities caused by physical or sensory impairment.

The Soto has been identified as one such precommercial product that fits this criteria and the VA is proceeding with an evaluation of it.

- The TTS is procuring two of the first units manufactured in the United States for compliance testing with the ANSI/RESNA W/C Standards; initially focused on standards for structural strength, durability, rolling efficiency, and stability.
- These first units will subsequently undergo human factor testing specific to propulsion, storage, and seating.
- Pending successful completion of the above, these chairs will incorporate design changes as a result of the laboratory and pilot test findings. Subsequently, an appropriate quantity will undergo consumer trials in a national multi-center evaluation throughout the VA.
- A design freeze incorporating changes as a result of the national study will guide the initial commercial production.

DISCUSSION

The Soto was designed to address the on-going desires of manual wheelchair users, that is, a lighter, easily foldable, reduced storage requirement and aesthetic looking wheelchair. The minimized storage requirement is critical for use in automobiles (especially as they become smaller).

The VA has identified the features presented in the Soto w/c as having significant potential benefit for veterans and non-veterans alike. This creative design warrants evaluation to determine its commercial viability and contribute to the evaluation of the wheelchair.

ACKNOWLEDGEMENTS

This technology transfer is sponsored by the Department of Veterans Affairs, Rehabilitation Research and Development Service, under the leadership of John W. Goldschmidt, MD, Director.

Saleem J. Sheredos, BEE, MHCA, Program Manager, Technology Transfer
VA Rehabilitation R&D Service
103 South Gay St., Balto, MD, 21202
(410) 962-2133

THE EFFECT OF THE FOLDING MECHANISM ON THE SLACK OF THE BACKREST FOR VERTICAL FOLDING WHEELCHAIRS

Pedro Barbosa Rodrigues, Arlindo F. Silva
Instituto Superior Técnico, Lisboa, Portugal

ABSTRACT

There are two distinctive design concepts for folding wheelchairs. The first in which the backrest folds on to the seat, and the second where folding is achieved by the two lateral sides of the frame being brought together.

For the second design concept there are again two basic possibilities. In one case the two lateral sides of the frame remain parallel to each other in the open, partly open and folded positions. In the other case the lateral sides of the frame are only parallel to each other in the open and folded positions. For this case the distance between the two lateral side frames measured at the top of the backrest when the wheelchair is partly folded can be greater than in the fully open position.

This effect leads to the occurrence of some "slack" to occur in the backrest material when the chair is fully open. The parameters controlling this effect are identified and a procedure for optimising the geometry of the wheelchair is presented.

BACKGROUND

There are two main types of vertical-folding wheelchairs as shown in figure 1. The main differences between these two types are: a) The folding mechanism employs on each side of the wheelchair two tubes which slide inside the tubes of the lateral frame. These tubes perform the function of connecting the two lateral side frames and simultaneously maintain at all times the parallelism between frames. b) A similar is achieved by a bar that pivots around two points in the wheelchair frame. However in this case only in the open and folded position is the parallelism between the two lateral side frames maintained(1, 2).

The present analysis relates only to the second type of wheelchair (b), because it is based on a commonly used design. It also shows some advantages when compared with the first type (a), among which the smaller amount of moving parts resulting in a lighter wheelchair. Nevertheless, this folding mechanism inevitably causes some slack to occur on the backrest material when the chair is in the fully open position.

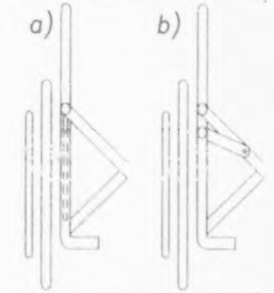


Fig. 1 - The two basic types of vertical-folding wheelchairs

This slack in the backrest material is caused by the lack of parallelism of the two vertical side frames, in the intermediate positions. This causes the distance between the two lateral side frames when measured at the top of the backrest to attain greater values in the partly folded position than in the fully open position. This deviation from parallelism can take values up to 8°. Assuming that the backrest material is not elastic this causes a slack of up to 21% in the backrest material in the open position.

This slack has two effects: firstly, the angle between the backrest and the seat is increased up to 5°; secondly, it may cause a large separation to occur between the seat and the backrest. Only the first effect will be analysed in this paper.

OBJECTIVE

The main objective of this study is to identify and minimise the parameters that affect the slack in the backrest material of a vertical non parallel folding wheelchair. These parameters can then be taken into account in the design and geometry of the folding mechanism.

METHOD

The approach used was to identify and analyse the involved parameters. Figure 2 shows from left to right, the geometry of a wheelchair in the open, partly folded and folded positions.

Parameter's A and Q are, respectively, the width of the opened and folded wheelchair, measured between the two vertical side frames. These are pre-defined design parameters. On the other hand, parameters E and F, are not pre defined and affect the length and the location of the pivoting points of bar 1 (shown in figure 2).

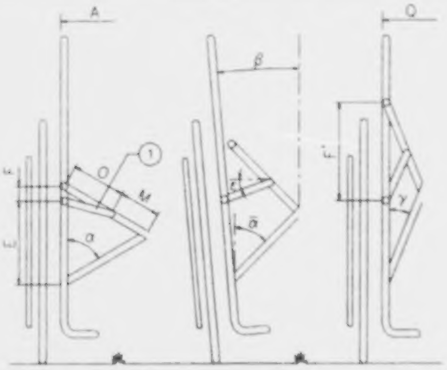


Fig. 2 - Ready-to-use, intermediate view and folded wheelchair

The value of O is calculated through equation 1. The positioning of bar 1 (dimension O and length L) is unique and is calculated interactively as a factor of parameters A, Q, E and F.

$$\frac{O\sin\alpha}{\sin\left[a\tan\left(\frac{O\sin\alpha}{-F+O\cos\alpha}\right)\right]}=\frac{O\sin\gamma}{\sin\left[a\tan\left(\frac{O\sin\gamma}{F-O\cos\gamma}\right)\right]} \qquad (1)$$

This will ensure that in both the opened and folded positions, the two vertical side frames are parallel. It does not, however, ensure this parallelism for the intermediate partly folded positions. Although parameter E does not appear explicitly in the expression, it is implicit in the calculation of angle α. In turn, the length and pivoting points of bar 1 govern the non-parallelism (angle β), as shown in equation 2. This angle is the parameter that governs directly the amount of slack in the backrest, in each of the partly folded positions.

$$\beta = a\cos\left[\frac{(2M+O)\cos(\overline{\alpha})-L\sin(\varepsilon)}{E}\right] \qquad (2)$$

RESULTS

As an example, the maximum value of β was calculated for two side frame geometry's with the same value of A and Q but different values of E and F(3). For each geometry the maximum value of angle β was calculated using equation (1) and (2).The results are shown in tables 1 and 2:

FRAME GEOMETRY 1		
DESIGN		MAXIMUM β
A	435mm	6.6°
Q	100mm	
E	220mm	
F	40mm	

Table 1 - The effect of the design variables in the maximum angle β for case 1

FRAME GEOMETRY 2		
DESIGN		MAXIMUM β
A	435mm	5.6°
Q	100mm	
E	180mm	
F	80mm	

Table 1 - The effect of the design variables in the maximum angle β for case 2

Figure 3 shows the variation of β for the frame geometry in table 1 as it changes from folded to completely opened.

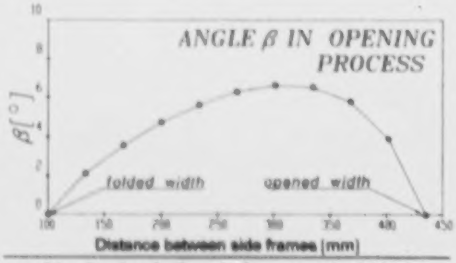


Fig. 3 - Angle β at different partly folded positions of the wheelchair

By means of maximisation of the maximum β the maximum amount of backrest slack can be calculated and is 92mm and 78mm respectively

BEST COPY AVAILABLE

for the two geometry's considered in tables 1 and 2.

DISCUSSION

The results show for wheelchairs of the type presented in figure 1 b) will inevitably have some degree of backrest slack. This slack is caused by the out of parallelism of the two vertical side frames in the intermediate positions between the open and folded positions as shown in figure 3.

The magnitude of the out of parallelism is a function of the design parameters, A, Q, E, and F as shown in figure 2. Values E and F can be optimised in order to minimise the amount of the backrest slack.

This backrest slack when minimised and quantified can be added to the backrest inclination thus being taken into account in the side frame back inclination in relation to the seat.

REFERENCES

1. Silva, Arlindo F., *Relatório de Projecto e Construção de uma Cadeira de Rodas Manual para Deficientes Motores*. Projecto Final de Curso, Instituto Superior Técnico, 1991.

2. Silva, Paula C., *Relatório de Projecto e Construção de uma Cadeira de Rodas Manual para Deficientes Motores*. Projecto Final de Curso, Instituto Superior Técnico, 1992.

3. Veenbaas, Roelof, *A Method for Choosing the Main Measures of a Hand Propelled Wheelchair System, Based on Anthropometric Sources and Multivariate Statistics*. Proceedings, ECART 2, May 26-28, 1993.

ACKNOWLEDGEMENTS

This research was carried out with the support of the Instituto do Emprego e Formação Profissional, Direcção de Reabilitação, Portugal.

Prof. Pedro Barbosa. Rodrigues
Instituto Superior Técnico
Secção de Projecto Mecânico
Av. Rovisco Pais
1096 LISBOA CODEX
PORTUGAL
Tel. 841 74 57
Fax. +351 1 847 40 45

DESIGN OF A LIFTING DEVICE FOR PEOPLE WITH MUSCULAR DYSTROPY

Karen L. West
Bath Institute of Medical Engineering Ltd
Wolfson Centre, Royal United Hospital, Bath, BA1 3NG, U.K.

ABSTRACT

A lifting device has been designed for use by adults with muscle weakness in their shoulder and pelvic girdle muscles, as a result of muscular dystrophy, (the "User Group") who have fallen over in their homes. A database was created of over thirty members of the User Group who were willing to be consulted during the project (the "Subjects"). A design specification was prepared with the assistance of the Subjects and three different designs of lifting device were explored using prototypes. One of the designs, a Rising Seat, was chosen for further development which will include its integration with a remotely controllable mobile base.

BACKGROUND

Muscular Dystrophy causes weakness and wasting of selected muscles, and is often degenerative. The User Group are adults, and have muscle weakness in their shoulder and pelvic girdles. They can walk but their muscle weakness sometimes causes them to fall over. Once on the floor, they find it very difficult to regain a standing position.

Most of the members of the User Group live in their own homes, and the majority rely upon other members of the household (the "Carers") to help them get off the floor when they fall over. The Carers are often faced with a dilemma; if they try and lift the person on their own they place themselves at risk of injury, however, calling neighbours or the emergency services, is time consuming and disruptive.

STATEMENT OF PROBLEM

The User Group require a lifting device to help them regain a standing position after falling over in their homes. The lifting device should promote the independence of the User Group, and reduce the likelihood of injury to the Carers. There are no devices presently available which adequately fulfil the needs of the User Group or the Carers.

RATIONALE

An understanding of the needs of the User Group was attained by interviewing nine of the Subjects in their homes, analysing preferred movement patterns using films of six of the Subjects moving from the floor to a seat, or from a seat to a standing position, interviewing the Carers, and health-care professionals. A further number of Subjects were interviewed upon the telephone. A questionnaire was also prepared for the purpose of ascertaining the frequency of falls, preferred methods of regaining a standing position, and lifting-related needs. Twenty-seven questionnaires were completed and returned.

Seven basic requirements of the lifting device were identified:

1. it should assist the user to regain a standing position after falling over;
2. the user should be supported using rigid platforms;
3. it should be suitable for use in a domestic environment;
4. using the device should require the minimum of muscle strength particularly during transfers on and off the device so that the user can be as independent as possible;
5. it should be portable so that a carer can bring it to the user or remotely controllable so that the user can call it to where they have fallen;
6. it should be compact and easy to store;
7. the cost of the device should be such that it is affordable by the User Group or supporting agencies.

Designing a Lifting Device

The design programme was split into three parts:

1. the design of a free standing lifting device;
2. the design of a remotely controllable mobile base which enables the user to call the device and instruct it to position itself next to where they have fallen;
3. the integration of the two designs.

FREE STANDING LIFTING DEVICE

Design

Three possible engineering solutions for the free standing lifting device were explored with the Subjects. They were the "Prone Lifter", the "Supine Lifter", and the "Rising Seat". The principal object of the lifting device is to help the user regain their feet after falling over.

The Prone Lifter prototype comprised a square platform (approximately 24 x 24 inches) which was cantilevered from a vertical linear actuator. The platform went down to floor level. The user lying upon the floor positioned their chest upon the platform. The platform then rose providing support to chest, buttocks, and knees. Once at an appropriate height it was proposed that the user would step out of the device.

The Supine Lifter prototype comprised a very low platform upon which the user could position their back and buttocks. The whole platform then rose using a "scissor jack" mechanism, changing from a flat platform to a high chair from which the user could slide into a standing position.

The Rising Seat prototype comprised a seat cantilevered from a vertical linear actuator. The 3/4" thick seat went down to floor level and was accessible from the front and both sides. It rose to a height of approximately 35" which was sufficient to enable users of average height to slide off the seat using one of the preferred movement patterns of the User Group. When not in use the device could be folded up thereby reducing the storage space required.

Evaluation

All of the lifting device concepts have been explored using prototypes. Four Subjects (three men and one woman) tried prototypes out in their homes, and the rest of the Subjects (there were over twenty other Subjects) were invited to comment.

The Rising Seat was preferred by the Subjects over the other two designs for four basic reasons: ease of use; compactness; flexibility; and, manoeuvrability. It became clear during the testing of the Prone Device that a special support structure was required to prevent too much pressure being placed upon the chest of the user but this made it difficult for the user to get free of the device once the lift was complete. The Supine Lifter was rejected because the Subjects felt it was big and ugly.

Development

The Rising Seat has been chosen for further development during which the possibility of using composites will be considered to reduce the weight of the device, and the design will be refined to make it suitable for long term testing in the homes of selected Subjects.

MOBILE BASE

Design

A first prototype has been constructed using two independently controllable DC motors mounted at the rear of the device, and a 12 volt battery. The two DC motors were used to drive, and steer the device. The footprint of the device was approximately the same size as the proposed footprint of the final lifting device. The device was remotely controllable using a radio frequency link, with either a joy stick or key pad.

Evaluation

The prototype of the mobile base was tried out by two Subjects in their homes, and it was found not to have sufficient manoeuvrability for a domestic environment.

Tests to find the most appropriate control interface were postponed until the next second prototype mobile base was ready.

Development

A further prototype of the remotely controllable mobile base which has the additional ability of being able to move sideways, and turn about its central axis, has been designed, and will shortly be evaluated.

Designs integrating the Rising Seat with the Mobile Base are being considered.

CONCLUSION

A number of different designs of lifting device have been explored with the assistance of members of the User Group, and a design suitable for further development has been found. The Subjects considered the designs in terms of ease of use (with particular regard to their disability), whether they would be happy with such a device in their homes, and the final cost of the device. Continual consultation between the engineers, the Subjects and their carers, and the use of numerous prototypes, was essential to ensure that the project progressed in the right direction.

It is anticipated that during the further development of the lifting device, particularly the development of the remotely controllable device, it will be the proposed working environment of the device which will present the greatest challenge.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Southern Trust.

Thanks to all the people who gave advice during the project, and all the people who tested the various prototypes.

Karen West
Design Engineer
Bath Institute of Medical Engineering Ltd
Wolfson Centre, Royal United Hospital
Bath, BA1 3NG, England, U.K.
Tel. 01225 824103 FAX 01225 824111

A BUGGY FOR TAKING DISABLED CHILDREN OVER SAND.

Michael R. Hillman, CEng,
Bath Institute of Medical Engineering Ltd.,
Wolfson Centre, Royal United Hospital, Bath BA1 3NG, UK

ABSTRACT

Wheel chairs are very difficult to move over sand or other rough terrain. This paper describes the design of a buggy chassis to enable a disabled child to be wheeled over sand. The chassis is made to accommodate the Maclaren Buggy Major.

STATEMENT OF PROBLEM

Many families with a disabled child in a wheelchair find visits to the seaside a difficult exercise. The disabled child must be treated as an equal member of the family, but getting a wheelchair over the sand to near the sea can be very difficult. Wheelchairs, though easy to move over smooth flat surfaces, are very difficult to move over rough terrain. Soft sand presents particular problems. Although a wheelchair can sometimes be dragged over the sand, this can be a very difficult operation, and often not possible at all for a heavier child.

BACKGROUND

Earlier work has investigated the problems of moving wheelchairs over sand [1]. This has included questionnaires to users and therapists, theoretical calculations, model tests and full scale trials. It was found that the diameter is the most important factor in reducing rolling resistance over sand. It was also found that pulling a chair is much more efficient than pushing. The device produced used a ball wheel attached to the front of a conventional adult wheelchair. Large diameter rear wheels were not modified. This device was effective in assisting mobility over sand. A pulling handle could be fitted at the front. However designing a device which could be fitted to a wide range of wheelchairs is proving difficult, though the work is continuing.

RATIONALE

In attempting to progress this work for children a new approach has been required. The ball wheel used earlier was of diameter 10". This will not fit between the narrower frames of a child's chair. Many disabled children are seated in a collapsible pushchair (Maclaren Buggy Major, Northampton, UK) which is a larger version of that available for infants. These buggies have relatively small diameter wheels both front and rear. Since diameter is of major importance in reducing rolling resistance over sand, it is not possible to ignore the rear wheels as has been done with the adult chairs.

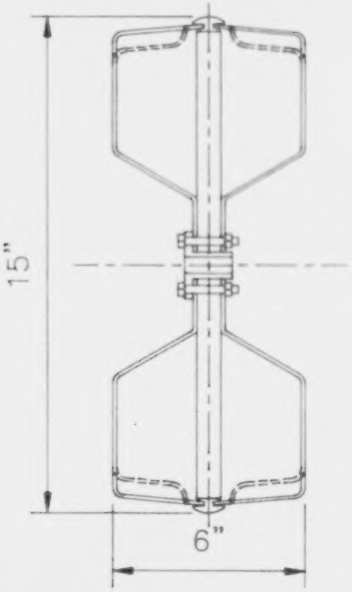
The basic concept has been to produce a chassis onto which a Maclaren Buggy Major will sit. Besides minimising rolling resistance, the requirements are for the chassis to be easily fitted to the buggy and to be easily collapsed for storage and transportation in the back of a car. In addition corrosion resistance must be considered carefully.

DESIGN

Wheel

The starting point of the design is the premise that the wheels should be of a large a diameter as possible. In addition the wheels should be of reasonable width and ribbed to assist rolling (as distinct from sliding) over sand. The wheels should also be as light as possible.

Since no commercially available wheels could be located, the prototype wheels were constructed of two vacuum formed halves attached to a wooden core (to provide strength) and with a rubber rib around the circumference for rolling over harder surfaces. The diameter (15") was limited by the size of our vacuum forming machine though this is near the size that would have been chosen as a compromise between large diameter for low rolling resistance and the requirements of small size for transportation and aesthetic appearance. The wooden core provides adequate strength and all parts (mouldings, rubber rib and axle) are secured to this. This construction, though slightly heavy, allows performance of prototypes to be determined without investment in expensive moulds.



Due to the shape of the buggy, and for good stability, it was decided that the chassis should have four wheels mounted on the outside. Since the chassis is to be used out of doors there is no absolute restriction on width. However the width was kept within reasonable limits by keeping the wheel width down to 6" and by having a recessed hub. It was decided that the buggy would be pushed in the conventional fashion, rather than pulled which would have been more efficient. Trials with the adult wheelchair device revealed that many wheelchair users disliked being pulled rather than pushed.

The wheels are not designed to swivel. Locating large diameter swivelling wheels is difficult and would have increased width. Earlier work had also shown that castoring over uneven surfaces did not work effectively. The buggy may be steered by lifting onto the rear wheels (a method regularly used for infant pushchairs) or over sand the wheels are able to slide sideways for manoeuvring.

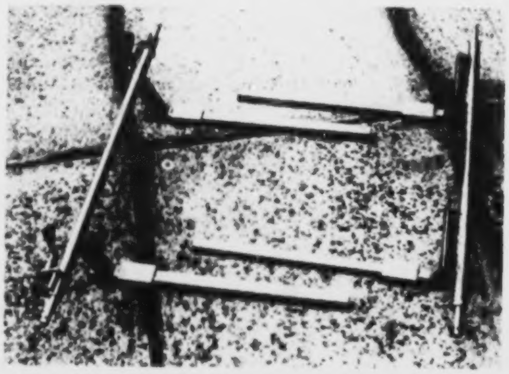
Chassis

The initial prototype was constructed very simply to test the performance of the wheels. No effort was made to make the chassis easily fitted or transported. Rather the buggy was bolted to a simple aluminium chassis using fairly crude "U" bolts. The device was tested over sand with a 10 stone adult in the chair (this is the stated maximum load of the buggy). Even with such a heavy load the device could be pushed over sand and manoeuvred without problems. There was no sign of the wheels digging into the sand, though there was appreciable, but not unacceptable, rolling resistance.

DEVELOPMENT

In order to carry out trials with disabled children and their families/carers it was necessary to redesign the chassis for the requirements of easy fitting and transportation. Since the initial trials were considered successful no change was made to the wheels and their positioning.

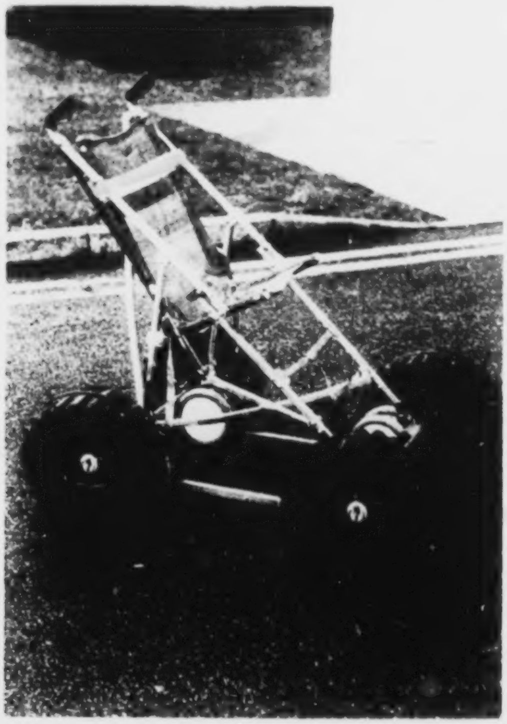
For fixing of the buggy in place, the chassis is made in two parts which can be slid together. When pushed together a spring clip locates the two halves. When secured in this position the cross tubes locate against the top of the buggy wheels keeping them securely fixed in place.



The chassis is made from square section steel tube plated with dull nickel chrome for corrosion protection. A brake mechanism is fitted to the rear wheels.

EVALUATION

The prototype has been tested by one family (Winter 94/95) on various beaches and paths in the Norfolk area of England. The device proved very successful. It was a great benefit not to have to lift the child out of the chair and to carry him and the pushchair bodily over the soft sand.



DISCUSSION

The device very successfully allowed mobility over sand which would not otherwise have been possible. Although width was not considered a critical factor in the design process, it was felt that it should be kept as narrow as possible for access through gateways and use on country paths.

Several detailed observations were made regarding the securing of the buggy within the chassis. These points have been noted, and will be incorporated in a revised chassis for further testing over the coming spring/summer.

An important requirement is that the device should be easily transported in the back of a car. The major factor affecting space requirements for transportation is the size of the wheels. There is no easy solution to this. However the four wheels are easily removed and may be slotted around other luggage. The two halves of the chassis do not take up much space.

Further development, leading to commercialisation will require the wheels to be lighter, and more easily produced. Rotational moulding is a technique which will be appropriate for mass producing the wheels, and this will be investigated.

CONCLUSIONS

A chassis has been successfully designed to enable a child in a Maclaren Buggy Major to be wheeled over sand. Further development and trials will take place before commercialisation of the device.

REFERENCES

[1] Wheelchair wheels for use on sand.
M Hillman, Med. Eng. Phys. 1994, Vol 16, May, pp 243-247.

Dr Michael Hillman, CEng,
Bath Institute of Medical Engineering Ltd.,
Wolfson Centre,
Royal United Hospital,
Bath BA1 3NG, UK
Tel. 01225 824103. Fax. 01225 824111
email: bime@bath.ac.uk

Playing Video Games For Fitness and Fun With Any Wheelchair

Narayan L. Gehlot[1,2], MSEE, Rory Cooper[1,2,3], Ph.D. and Rick N. Robertson, Ph.D.[1,2,3]
University of Pittsburgh
School of Engineering[1], School of Health & Rehabilitation Sciences[2] & VA Medical Center- Highland Park[3]

Abstract

This paper discusses an innovative application of technology to facilitate recreation and fitness by manual wheelchair users. A complete electrical system is build which can be readily mounted on any wheelchair for recreation and fitness due to technological advances in semiconductors technology and particularly in the field of dynamic resistors. The existing technologies are briefly reviewed, different alternatives discussed and complete electronic details are given. A cost effective system imitating a video game joystick using both wheels of a wheelchair is designed and is being prototyped.

Background

An individual's ability to exercise can be severely limited by paralysis. Many people with disabilities are sedentary because options and opportunities to participate in health promoting physical activities are limited, and for many people wheelchair mobility does not provide a sufficient source of motivation to exercise. This can have adverse health effects, such as cardiovascular disease, muscle atrophy, osteoporosis, and decubitis ulcers [1]. There are important advantages to increased aerobic fitness for people with spinal cord injuries: decreased risk of heart disease; higher motivation to continue therapeutic exercise; an increase in wheelchair mobility; and increased independence [1]. What a computer game offers is the immersion of the player in a virtual world that can be manipulated.

Commercial computer games have received some attention as therapeutic exercise tools. A Nintendo controller was modified to be used with a power wheelchair sip and puff input device [2]. Two people with complete quadriplegia were able to successfully play video games with this system. Yankelevitz used modified computer input devices to show that the ability to play computer games skillfully are very important in improving motor skills, coordination, and self-esteem among some people with severe disabilities [3]. Chung developed a computer game for use with stationary exercise equipment which is controlled by the player's heart rate [4]. The goal of the game is to keep the heart rate as close as possible to the target value. Playing video games as a form of exercise may give many people a chance to be healthier and happier.

Method

Any PC or MAC can be used for playing a video game [5,6]. A video game that requires a joystick for playing is slightly more complicated than the one played with a mouse or keyboard. The principle of interfacing a video game card and its operation are discussed in [5,6]. A game card has eight input lines that are read by an IN (80x86 microprocessor) command from address 201Hex. Four of these inputs are resistive pull-ups measured to +5 volts DC. The signals going into the pull-ups come from an NE558 quad timer configured as four one-shot outputs. The signals at two of these resistive inputs are read from the potentiometers of a joystick into the timer and are converted into digital pulses with duration proportional to the resistive load of the associated joystick (JS) potentiometers. The pulse duration at each pull-up is defined by Eqn. (1); where R (Rx or Ry range from 0-160K ohm) is the resistance value for the JS (X or Y motion of JS) potentiometer. This value depends on the position of the joystick with respect to the JS center or null.

$$\text{Pulse Duration} = 24.2\ \mu s + 0.011 * R\ \mu s \quad \text{Eqn. (1)}$$

Interfacing the optical encoder (OE) outputs to the game control card is not straight forward. As an alternative the wheel rotation speed and direction of motion can be obtained by a tachometer. Due to disadvantages of a tachometer this technique is not discussed further.

Pushing a manual wheelchair rotates a roller. As the wheelchair is pushed the optical encoders mounted on the roller shaft converts revolutions per minute to pulses. The optical encoder output consists of a set of three pulses-A, B and I (details can be found in [7]). The challenge is to convert optical encoder outputs to a variable resistance as required by a video game card described above. A complete block diagram of the concept used in this design is shown in Figure 1. From the blackbox shown in Figure 1, the following functions are to be realized:

- Frequency-to-Voltage (F->V) conversion,
- Voltage-to-Resistance ((V->R) conversion
- motion direction detection for each wheel and
- variable challenge provision.

Frequency-to-Voltage (F->V) conversion Rotation of each drive wheel is indicated by the encoders and their output is a frequency signal (the frequency of encoders and the frequency used in the game card are not related). The frequency signal is required to be converted to a voltage signal which then can be used to control a dynamic resistor. Different devices are available for measuring and converting frequencies depending on the required accuracy, response, range and output format. Existing technologies for converting (F->V) and their pros and cons can be found in [8]. Measurement and conversion of frequency to voltage can be done by three different methods- Events Per Unit Time, Charge Pump Method and Reciprocal Method [8]. A useful technique for wider range and higher accuracy is available when a microprocessor is used. The CMS1000 and CMS1010 [8] are single IC implementations of the digital portion of (F->V). The CMS1020 [9] incorporates all of the features a digital (F->V) in a single 40 pin package. In the current design the OE used outputs a linear voltage proportional to the speed of the motor along with pulse A and B, which are essential for determining direction. The ripple on the output of the linear voltage is about 10 mV and does not affect the current application.

Voltage-to-Resistance (V->R): A constraint in this project is that the game cards should not be modified to keep options open for playing any video game on any PC. Use of microprocessor or a dedicated card will be more expensive and would require each user to install it in a PC. Hence a dynamic resistance is required which will vary according to the direction and frequency observed of the OE. The goal has been to use off the shelf electronics and minimum hardware and software.

Dynamic Resistor: An array of resistors with a wiper tap that can be selected with digital control offers many advantages. These are referred to as digitally controlled potentiometers. Logic circuits, counters, and memory circuits are often teamed up with resistor arrays to accomplish an approximation of potentiometer control. Recently, a few manufacturers have introduced devices which incorporate many of these functions in one device. Examples are Xicor's X9CMME, Toshiba's T09169AP, Analog Device's (AD8402/8403 not yet released) and National's LMC835. The Toshiba and National parts are designed around specific audio applications and are distinctively different from the Xicor device and require a microprocessor to use them. They incorporate features that lend well to audio designs, but are not intended for general purpose potentiometer replacement. Moreover, they offer only a limited number of wiper positions. Xicor's X9CMME [9] combines a single 99 position (a resolution of 100K ohms/99=1.1K ohms) potentiometer with three line digital controls. Dynamic potentiometer (DP) contains an internal counter circuitry for wiper position control. This part also incorporates nonvolatile memory to retain wiper position. It has been designed as a digitally controlled replacement for the mechanical potentiometer. With its conventional three terminal potentiometer design, it integrates easily into existing analog designs such as a video JS.

For the current project X9C104 is used, (refer to [10] for complete details). As per Xicor all nonvolatile memories are designed and tested for applications requiring extended endurance and data retention (100 years). The non-volatile memory of X9C104 is programmed for 50K ohms.

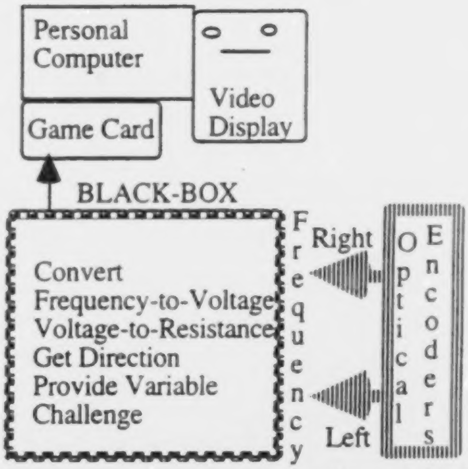


Figure 1. Block diagram showing the need for the **BLACKBOX** and its functions to play video games on any PC with a manual wheelchair wheels.

Device operation: (Caution:) The electronic switches on X9CMME operate in a "make before break" mode when the wiper changes tap positions. If the wiper is moved several positions multiple taps are connected to the wiper for T_{low} (INC to Vw change). The R_{TOTAL} value for the device can temporarily be reduced by a significant amount if the wiper is moved several positions. This is not a problem since our system is slow. The end-to-end resistance of the array will fluctuate once Vcc is removed. It only takes about 400 micro-seconds for the DP to stabilize to the stored value (50K) on power-up. Once the power is turned on the DP is centered at 50K automatically from its non-volatile memory. When connected to a game card, this value of 50K resistance will generate a certain Pulse Width (Duty Cycle) at a frequency predetermined by the game card. How the digital potentiometer works is explained below:

Connect a pull-up resistor of (500 ohms) to each of the Pins-1, 2, 7., hence all these PINS are normally active HIGH. Generate a logic (High/Low) from A and B outputs (direction of wheelchair motion) signal of OE and connect it to U/D (Pin-2). Connect a CS (Pin-7) to GND permanently. Connect pin V_H to +5 Volts and V_L to the input to the game card. Connect Pin-4 to GND and Pin-8 to +5 Volts (Vcc). The wiper moves **up** when U/D (Pin-2) HIGH (>3.0 Volts), since CS (Pin-7) is GND. The wiper moves **down** when U/D (Pin-2) LOW (GND), since CS (Pin-7) is GND. Each step of the clock on INC (Pin-1) will produce a 1% change in the DP. A digital switch is used to generate INC (Pin-1) clock signal as described below:

The analog voltage from OE is fed to a comparator. The threshold of the comparator is variable and will be used as a variable challenge controller knob. If the threshold is set at 4 volts the user will have to go at full speed > 1KHz (it can be changed) to generate any output from the comparator to play video games. The output of the comparator is used to feed in the clock signal to INC (Pin-1) with an AND gate. The clock signal is generated from a 555 timer chip. This clock signal frequency will be a second challenge variable, since a faster clock determines a quick response. The dynamic pot increments or decrements its resistance by 1% for each clock pulse transition from HIGH to LOW on INC (Pin-1) and hence depending on the duration of the clock, the rate of change of resistance will vary. This in turn will again control the rate at which the video game responds.

The video game also requires a firing signal. The continuous firing signal will be generated using a 555 timer. The firing rate can be same as the INC (Pin-1) clock or can be different. Manual firing is not permitted since both hands are to be used for wheel rotation for maximum fun and fitness. Both the channels have identical electronics as discussed above.

Results

A video game playing input device imitating a video game joystick has been designed, analyzed and is currently being build. A large number of individuals and institution could potentially use this development for recreation and fitness of wheelchair users. After a thorough testing of the prototype it will be ready for commercial production.

Discussion

Exercise compliance is a difficult problem faced by therapists and physicians when rehabilitating a wheelchair user. Many wheelchair users are uninterested in participating in organized wheelchairs sports. Others may wish to exercise indoors. In institutional settings exercise compliance becomes a greater issue as patients complain that arm ergometers and wheelchair rollers are boring and monotonous. Patients often only attend therapy when supervised, and frequently require prodding from therapists. However, many patients will voluntarily play video or arcade games for hours. Combining video games and wheelchair pushing should provide motivation for exercise or at least provide therapeutic exercise benefit while being distracted by video games. Further testing is required to determine the influence of the wheelchair to video game interface on therapeutic exercise compliance. Selection of video games must also be explored.

REFERENCES

[1] Glaser, R.M. "Arm exercise training for wheelchair users". Medicine and Science in Sports and Exercise 21(5):S149-57, 1989.

[2] Caves, K.M. "Modified Nintendo Controller: An application of integrated controls." Proceedings 15th Annual RESNA International Conference, Toronto, Canada, June 1992. pp. 551-552

[3] Yankelevitz, Ken S. "Adaptive controllers for video games and computers." RESNA Proceedings 6th Annual Conference on Rehabilitation Engineering, San Diego, CA 1983. pp.

[4] Chung, B.H. "A video game to promote aerobic activity for the disabled." Proceedings 15th Annual RESNA International Conference, Toronto, Canada, June 1992. pp. 252-254

[5] Eggebrecht, L.C. Interfacing to the IBM Personal Computer. Howard W~ Sams & Co., Inc., Indiana, 1983.

[6] A. N. Vosse. "An Interactive Video System for the Wheelchair Dynamometer". MSBME Thesis, California State University, Sacramento, 1993.

[7] Computer Optical Products, Inc., Manufacturing: 9305 Eton Av., Chatsworth, CA, USA

[8] Application Notes 001, "Measurement of Low Frequencies Requires Careful Consideration", Custom Micro Systems, Inc., Box 9472, Livonia, MI 48151

[9] Xicore, Non-Volatile Solutions Data Book, 1992. pp. 4.1-4.13

Acknowledgments

This work was partially supported for hardware cost by the Human Engineering Research Laboratories.

Narayan Gehlot, MSEE, Ph.D. (candidate) EE
University of Pittsburgh, School of Engineering
School of Health & Rehabilitation Sciences
915 William Pitt Way, Pittsburgh, PA 15238
Phone: 412-826-3138, Fax: 412-826-3143

A NEW DEVICE FOR CONTINUOUS MEASUREMENT OF THE LUMBAR SPINE

Todd MacKenzie & Beth Devino
Vermont Rehabilitation Engineering Research Center
University of Vermont
Burlington, VT 05401

Abstract

The Effectiveness of seating evaluations for individuals in wheelchairs may be compromised by the uncertainty of lumbar spine posture. A device for measuring lumbar lordosis continuously (Lordosimeter) was developed and evaluated. The tool is capable of obtaining and recording skin surface contours over a wide range of postures. Current direct surface measurement methods (e.g. flexible ruler, inclinometer) are safe and easy to use. However, application is typically limited to the standing posture and laboratory-based seated experiments. Lumbar lordosis is widely regarded as desirable while sitting, and this device could prove useful to help therapists evaluate spinal posture. Additionally, it may be used as a biofeedback tool to help clients identify a stable seated position.

Background

Increased demand for improved, comfortable wheelchair seating has led to the current wide variety of products to meet specific needs of wheelchair users. Additionally, therapists have sought specific product features to maintain stability, support, and/or control for their clients. In recent years, therapists have increased their seating evaluation skills by participation in manufacturer in-services, trade shows, and conferences on the health and comfort requirements of users. Despite these developments however, there is currently no tool to help therapists measure and maintain a client's neutral lumbar lordosis. The Lordosimeter is well-suited for lumbar lordosis measurement in a seated position with rigid, foam, or gel backrests. The slim, non-invasive profile should not affect user comfort or daily living patterns. The Lordosimeter is intended as both a field measurement tool and as a research evaluation device. It therefore differs from existing range of motion and lordosis measurement techniques (3,5,6). The device could be applied to measure lumbar shape, evaluate seating contour features, or to help identify various supported postures. Historically, two dissimilar opinions have been set forth regarding the preferred magnitude of lumbar lordosis for the seated posture. Some researchers believe that flexed postures and the resulting decrease of lumbar lordosis decreases the stress on posterior portions of the vertebral disc (1). Adams suggests that such flexed postures could improve intervertebral disc nutrition and result in decreased low back pain. Other investigators have considered lumbar lordosis desirable and have suggested that it can, and should, be maintained while in the seated posture. Over 100 years ago, Staffel, (7) was an early proponent of a maintenance of seated lordosis as close as possible to that of standing. That is, lordosis should be preserved and all efforts should be made to prevent the spine from "straightening out". More recently, researchers have extended the argument for maintaining lumbar lordosis on the basis of minimizing intradiscal pressures (2). Andersson shows that disc pressure is lower in the standing position than in unsupported sitting positions. Among those unsupported postures, disc pressure is the lowest in the presence of lordosis and highest in kyphotic postures.

Statement of Problem

Low back pain has been identified as a secondary disability among wheelchair users. Additionally, low back pain can aggravate the seating and positioning challenges addressed by the therapist. Existing wheelchair seating, evaluation, and fitting technologies do not permit measurement of lumbar posture. Neutral lumbar lordosis has been identified as essential to maintain comfort and health. The Lordosimeter could be used to evaluate and maintain lumbar posture.

Design and Development

A quantity of 10 strain gages (Micromeasurements Inc.) were mounted along the centerline length of stainless steel shim stock .008" thick and 5/8" width. Total instrumented length of the Lordosimeter was approximately 11 inches. Each gage was configured as the active element in a Wheatstone quarter bridge circuit and wired to a P-3500 strain output indicator manufactured by

Micromeasurements Inc. A three-wire Wheatstone Bridge configuration was used to minimize the effects of temperature drift.
The strain gages were configured to measure bending and the incremental changes in gage output voltage were calibrated to measure lumbar flexion and extension. In this experiment, the steel shim stock (i.e. rectangular solid) was subjected to a complex loading situation in which the upper surface was in tension and the lower surface was in a state of compression. Since the material is homogeneous, this loading scheme resulted in an unloaded central axis. In this loading scheme, the top surface, bottom surface, and neutral axis each had an independent and concentric radius of curvature.

The gages on common sides of the Lordosimeter had to be accurately affixed to the device with a high degree of precision. They were mounted within close tolerance of parallel, alignment "by eye" was not adequate for this application. The present study revealed the following technique to ensure high precision in the mounting of the gages. Centerlines on the stainless steel and corresponding lines on a plastic work surface were found to ease the task of proper alignment. Double gages can be considered for use in later models to avoid this alignment issue. Such gages were not used in these experiments due to cost and long lead times.

The device gages were affixed in 1" increments from approximately T-12 to S-1. Device contact was maintained with the concave portion of the lumbar spine by constructing a narrow channel through which the Lordosimeter passed. The resulting configuration provided a low friction surface and accommodated the effects of skin distraction with forward flexion.

Corrections for the thin cross-section and transverse strain were applied according to Dally(4) as were standard design principles to minimize electrical noise.(4)

Evaluation

Preliminary bench testing evaluated materials, voltage response, and repeatability. For the purpose of this pilot study, a series of voltage readings was obtained from each of ten Wheatstone bridges for three anatomical postures (standing-flexed, standing, and sitting).
To assess the validity of this device, the effects of posture on voltage were studied. It was hypothesized that the mean strain for each of the three postures would be different. It was further hypothesized that the maximum mean strain would be associated with standing subjects and a minimum mean strain would be measured on subjects in the forward flexed posture.

Data collection was simplified with a Micromeasurements SB-10 switch box designed to permit convenient cycling between the ten gages. The Lordosimeter was affixed to the subject (170 lb, 23 year male) with large sample pieces of EMG electrode material (Uni-Patch Inc.).

The ten bridges were balanced on a flat surface and locked. A series of 11 trials was conducted in which the subject was directed to assume postures of sitting-neutral (4 trials), standing-neutral (3 trials), and standing-flexed (2 trials). Single trials were also obtained for sitting-flexed and "poor posture" but were not included in the statistical analysis. Statistical analysis included a test of equal means among strain for the three postures described above. Box plots of voltage grouped by posture suggested unequal variance. However, the null hypothesis of equal variance was rejected with Hartley's Test, thus a conventional analysis of variance was performed. Analysis of variance showed differences in voltages among the three postures (p<.001). Results from Tukey's Studentized Range Distribution Test show that there was a significant difference in means between all three postures.

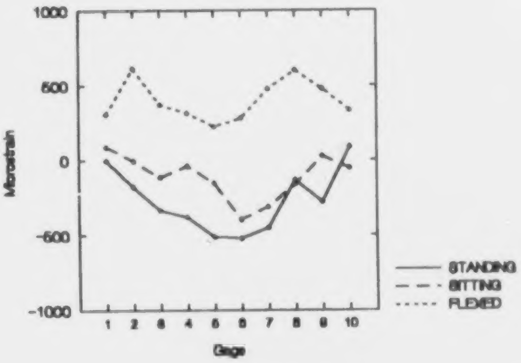


Figure 1: Microstrain for 10 gages over three postures

Mean strain by gage and posture are summarized in Figure 1. Negative values indicate lumbar lordosis and positive values indicate kyphosis.
The sign and magnitude of the voltage output is in agreement with the literature cited above. For example, the standing posture exhibits the most

negative voltage and therefore the maximum lordosis. As the subject moves to a seated posture, the magnitude approaches zero which is consistent with the literature.

Discussion

The results show a unique strain output for each of the three positions described above. Showing that the device was capable of discriminating among the three postures was critical prior to conducting a full-scale analysis of the device validity.

The goal of this development project was to create a device that accurately and reliably measures the curvature in the lumbar spine. The encouraging results are preliminary and the Lordosimeter validity has not yet been confirmed. Future studies will evaluate the device validity relative to X-ray measurements of the lumbar spine. Current prototypes include the use of the full Wheatstone Bridge to compensate for the effects of temperature and torsion.

References

1. Adams MA, Dolan P, Marx C, Hutton W: An electric inclinometer technique for measuring lumbar curvature. Clin Biomechanics 1(3):130-134, 1986
2. Andersson GBJ, Ortengren R, Nachemson A, et al: Lumbar disc pressure and myoelectric back muscle activity during sitting. IV: Studies on the car driver's seat. Scan J Rehab Med 1974; 6:128.
3. Boocock MG, Jackson JA, Burton AK, Tillotson KM: Continuous measurement of lumbar posture using flexible electrogoniometers. Ergonomics 37(1):175-185, 1994
4. Dally JW, Riley WF: Experimental Stress Analysis. McGraw-Hill, San Francisco. 1991
5. Israel MA: A quantitative method of estimating flexion and extension of the spine--A preliminary report. Military Medicine 124:181-186, 1959
6. Loebl WY: Measurements of spinal posture and range of spinal movement. Annals of Phys Med 9(3):103-110, 1967
7. Staffel F: Die Menschlichen Haltungstypen und ihre Beziehungen zu den Rückgratsverkrümmungen. Wiesbaden, Bergmann, 1889. Translated in Bonne, AJ: On the shape of the human vertebral column. Acta Orthopaedica Belgica, 35:567-582, 1969

Acknowledgements

Funding for this project was provided by the National Institute on Disability and Rehabilitation Research, US Department of Education (H133E30014-95).

Todd MacKenzie
Vermont Rehabilitation Engineering Center
University Health Center
1 South Prospect Street
Burlington, VT 05401

IMMEDIATE IMPROVEMENTS IN WHEELCHAIR MOBILITY AND COMFORT WITH USE OF THE ADJUSTABLE BACK SUPPORT SHAPING SYSTEM

Denise A. Chesney, Lynn Hsu, Wayne Wright, and Peter W. Axelson
Beneficial Designs, Inc.

ABSTRACT

Sling upholstery is a cost effective and creative solution to facilitate seating in a folding wheelchair structure. However, sling upholstery stretches and, even if it is adjustable, only facilitates postural positioning to a limited extent. A Back Support Shaping System that utilizes postural support pads in combination with tension straps can be fitted behind the back upholstery in wheelchairs with sling upholstery. Twenty-seven subjects have been fit and evaluated with an adjustable back support shaping system. These subjects will be using the Back Support Shaping System for a period of one year. Immediate results were measured with regard to mobility and comfort. The speed and strength with which the subjects propelled their wheelchairs up a ramp increased, as did their comfort These changes are attributed to improved posture, increased rigidity of the wheelchair system, and changes in the weight distribution of the chair.

BACKGROUND

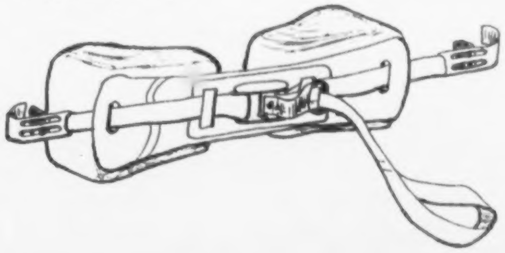
The importance of postural support to sustain appropriate pelvic alignment and spinal positioning when sitting is an issue which is receiving increased attention in populations both with and without mobility impairments. The problem of poor sitting posture is particularly acute in wheelchair users. In people with spinal cord injury, posterior tilt of the pelvis when sitting has been demonstrated to be an average of 15 degrees greater than in non-injured controls (1).

One factor contributing to this problem is the use of sling upholstery, which provides inadequate postural support even when new, and stretches to a position allowing even greater posterior pelvic tilt within two to three months of use. The correlation between use of sling upholstery and rounded sitting posture is clinically accepted (2,3). Another significant factor is the impairment of the trunk musculature which ordinarily provides stability in an erect position; this impairment frequently leads to the choice of a more rounded sitting posture by wheelchair users in order to take advantage of the greater passive stability this position provides.

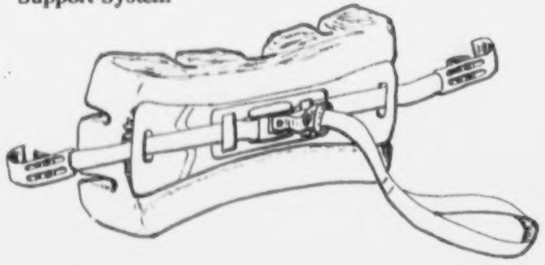
The disadvantages of the posteriorly tilted, rounded position are the same for people with and without disabilities: discomfort, including neck, back, and shoulder pain; contribution to the development of alignment dysfunction of the spine and pelvis; and possible decreased efficiency of upper extremity and respiratory function. Functional compromise may result from decreased mechanical advantage of the involved musculature, and from mechanical restrictions of mobility in the joints of the spine, ribcage, and shoulder girdle.

The Back Support Shaping System was developed to provide postural support in conjunction with sling upholstery and to allow adjustability by the user throughout the day to optimize both posture and stability as needed during varying functional activities. A modular system consisting of a single lower support pad and two upper support pads was developed.

Full Back
Support System



Low Back
Support System



RESEARCH QUESTIONS

Over the course of this two year research study, a variety of questions relating to the design of the back support system and to the responses of 40 subjects to its use over the course of the one year clinical trial will be addressed. Changes in posture and in function will be quantified, and the relationships among the different areas of investigation for subjects in various functional categories will be examined. Two questions have been isolated for analysis immediately upon initiating use of the system:

1) Can improved comfort be demonstrated with the

addition of the Back Support Shaping System to wheelchair seating systems with sling upholstery?

2) Can increased efficiency of wheelchair propulsion be demonstrated with the addition of the Back Support Shaping System to wheelchair seating systems with sling upholstery?

METHOD

Twenty-seven subjects (22 male; 5 female) were fitted with the Back Support Shaping System and immediately underwent preliminary functional testing with and without use of the back support system. This group included 22 individuals with spinal cord injuries (13 with paraplegia and 9 with quadriplegia), 2 with Multiple Sclerosis, 1 with Post Polio Syndrome, 1 with Spinal Muscular Atrophy, and 1 with Failed Low Back Syndrome. Ages ranged from 21 to 66 years, with a mean of 35.9 years. Four subjects used a powered chair as their primary chair and the remaining 23 subjects were manual wheelchair users.

Each subject was fitted with a back support system. The Low Back Support System was utilized with 20 subjects, and the Full Back Support System was used with 7 subjects. The appropriate system was selected for each subject based on the height of their wheelchair back upholstery, their functional level in terms of balance and stability, and their comfort. The exact height of each strap relative to a given subject's back was determined based on evaluation of the segmental flexibility of that subject's spine, and on the subject's feedback regarding comfort. Once the height of the strap was fixed, the amount of tension in the strap(s) was chosen for the initial testing based on comfort and on the optimization of posture. Following testing, the tension remains adjustable by each subject at any time.

Seat and back pressures were measured with the Force Sensing Array (Vistamed) to rule out any evidence of increased risk of skin breakdown with the back support system (None of the subjects showed increased risk of skin breakdown based on these data).

Subjects subsequently underwent mobility testing to determine whether wheelchair propulsion became more efficient with the back support system in place. Each manual wheelchair user was instructed to propel 3 meters up a standard 1:12 ramp at maximum speed. Three trials were conducted without the back support, then with the support; any influence of fatigue would therefore work against the hypothesis of increased efficiency with the back support. The time required to propel 3 meters was recorded.

Similarly, each subject was instructed to propel the maximum distance possible up the same ramp in one push. As previously, three trials were performed without and then with use of the back support, and the distance traveled each time was recorded.

At the end of the initial evaluation, subjects were asked to fill out a questionnaire, rating their comfort with and without the back support on a visual analog scale.

RESULTS

Wheelchair Propulsion Speed

Use of the Back Support System improved the speed the subjects could propel their wheelchairs up the standard ramp with a mean decrease in time of 4.6% (s.d.=7.7). Although the variance of the results was great, the improvement was statistically significant (one-tailed t-test, $\alpha=0.05$). Eighteen (78%) of the subjects were able to propel up the ramp faster when the back support was used.

Wheelchair Propulsion Strength

On average, the 23 subjects that performed this test were able to push 11.7% (s.d.=16.4) further up the standard ramp with use of the back support. The propulsion strength of one subject improved 68%, when the back support was in place. Only two subjects actually decreased their performance on this test with the back support on their chair. A one-tailed t-test revealed that this improvement and increase in propulsion strength was statistically significant ($\alpha=0.05$).

Comfort

Comfort both in the lower back area and in the shoulders and neck was improved significantly with use of the Back Support System (one-tailed t-test, $\alpha=0.05$). None of the subjects reported that the back support decreased their level of comfort. Overall, increased comfort was reported.

DISCUSSION

Two factors were originally hypothesized as contributing to an increase in wheelchair propulsion efficiency.. First, the changes in spinal curves and scapular position with the use of the Back Support System put the body in a more efficient position for upper extremity muscular function.

A second factor that increases propulsion efficiency is an increase in the rigidity of the wheelchair system. The back support created a more rigid seating system compared to that provided by sling backrest upholstery only. Less give in the wheelchair system means that more of the energy expended by the rider went into propulsion and less was lost in the flexing of the backrest.

A third factor was also identified as influencing propulsion efficiency for some subjects. The change in posture encouraged by the back support generated a

304

forward weight shift, shifting the position of the subjects forward relative to the main rear wheels. This change influenced propulsion efficiency in two ways. First, the adjustability of the Back Support System allowed each user to optimize his/her positioning to achieve maximum functional strength. Second, this change in positioning increased the rearward stability of their wheelchair system. This enabled them to exert more force into each push since the wheelchair had less tendency to go into a wheelie position.

Use of the Back Support System (1) promoted a more upright posture, (2) increased the rigidity of the wheelchair and improved functional posture, and (3) shifted the user's center of gravity forward resulting in improved propulsion speed and strength.

The results of this research demonstrated that use of the adjustable Back Support System provided immediate improvements in propulsion efficiency and comfort for persons who use wheelchairs with sling backrest upholstery.

REFERENCES

(1) Hobson, D.A. "Seated Lumbar/Pelvic Alignment: A comparison between Spinal Cord Injured and Non-Injured Groups," *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, June 1989, pp. 161-162.

(2) Bergen, A., Presperin J. *Positioning for Function: Wheelchairs and Other Assistive Technologies*. Valhalla, NY: Valhalla Rehabilitation Publications, Ltd. 1990

(3) Presperin, J. "Interfacing Techniques for Posture Control" *Proceedings of the 6th International Symposium*, Vancouver, B.C., Feb. 1988, pp. 71-75

ACKNOWLEDGMENTS

This research was funded by NIH-NICHD-NCMRR Phase II SBIR grant # 2 R44 HD29983-02

Collaborating Institutions:
Department of Veteran's Affairs Medical Center, Palo Alto, CA
Ralph K. Davies Medical Center, San Francisco, CA
Santa Clara Valley Medical Center, San Jose, CA
Stanford University Rehabilitation Engineering Center, Stanford, CA

MODIFICATION OF THE LOCAL EFFECTIVE STIFFNESS OF SEATING FOAM BY HOLE DRILLING

Tommy E.T.Kang[1], Arthur F.T.Mak[1] and H.C.Man[2]
[1]Rehabilitation Engineering Centre, Hong Kong Polytechnic University
[2]Department of Manufacturing, Hong Kong Polytechnic University

ABSTRACT

Polyurethane (PU) Foam blocks before and after holes-drilling were tested. The variation of supporting properties with the loss of surface area due to holes-drilling were studied. The results indicated that the percentage loss of Indentation Load Deflection (ILD) was linearly proportional to the percentage loss of foam surface area. The changes in the supporting properties of PU foam blocks associated with static degradation and dynamic degradation were also examined. The supporting properties of PU foam changed significantly with the duration of static compression and with the number of cycles of dynamic compression.

INTRODUCTION

Prevention of pressure sores remains an important issue in rehabilitation, especially of patients who are spinal cord injured (SCI) wheelchair user[1][2]. Wheelchair cushions make of polyurethane (PU) foam are frequently used to distribute pressure and reduce the risk of ulcer formation. As flat PU foam cushions cannot properly envelope the buttock, they cannot effectively redistribute the cushion-buttock interface pressure. Modification of foam properties by surface cutting has been reported recently[3]. This study investigates another cushion surface modification method - hole drilling. The objective of this paper is to study the relationship between the supporting properties and loss of surface area.

METHODOLOGY

Foam blocks with dimension 4cm*4cm*5cm were tested before and after holes-drilling in a Hounsfield Material Testing Machine. The compression test experiment was based on ASTM D3574-91. The procedures were as follow: (1) preflex the foam to be tested by twice lowering the indentor foot to a total deflection of 75% in order to increase the reproducibility of the readings, (2) allow the specimen to rest 6±1 min after preflexing, (3) indent the specimen at 50mm/min to 25% of the foam thickness, wait for 60s and than note the 25% ILD value, (4) without removing the specimen, increase the indentor foot to 65% deflection, (5) allow the indentation force to drift while maintaining the 65% deflection, and again wait for 60s and than note the 65% ILD value. All the experiments were done under temperature 20±1 °C and relative humidity 60±5%[4]. The results of the 25% Indentation Load Deflection (ILD) values and 65% ILD values were reported. The % loss of ILD values were plotted against the % loss of foam surface area due to holes-drilling.

Where

% loss of foam surface area = (foam surface area before drill - area remove by drill)/foam surface area before drill,

% loss of 25% ILD = (25% ILD before drill - 25% ILD after drill)/ 25% ILD before drill

and

% loss of 65% ILD = (65% ILD before drill - 65% ILD after drill)/ 65% ILD before drill.

The changes in the support properties of PU foam blocks associated with static degradation and dynamic degradation were also conducted. In the static degradation study, the foam blocks were compressed to 65% of its original thickness for 7 days, 30 days, and 95 days. Ageing was not considered separately in the experiment[5]. The 25% ILD values were obtained through the above procedures. In the dynamic degradation study, the foam blocks were compressed to 50% of its original thickness at ~1Hz for 8000 cycles and 80000 cycles. The 25% ILD values were obtained as above.

RESULTS AND DISCUSSIONS

An increase in the number of holes per unit area decreased the average pressure on the foam surface both at 25% ILD and 65% ILD. The percentage loss of ILD with the percentage loss of foam surface area was shown in Figure 2. The results indicated that both the percentage loss of 25% ILD values and 65% ILD values were linearly proportional to the percentage loss of foam surface area with a slope of 1.58 and 1.72 for the 25% ILD and 65% ILD respectively. A two factor factorial analysis was performed. The difference between the % loss of 25% ILD and the % loss of 65% ILD was not significant at the 0.01 level. By combining the results from both the 25% ILD and 65% ILD studies, we may express (% loss of ILD) = 1.65 x (% loss of foam surface area).

Figure 1. Pattern of holes-drilling

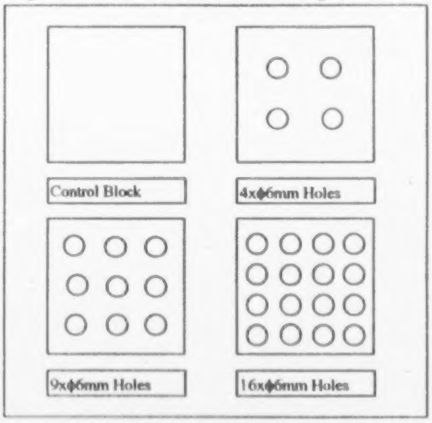
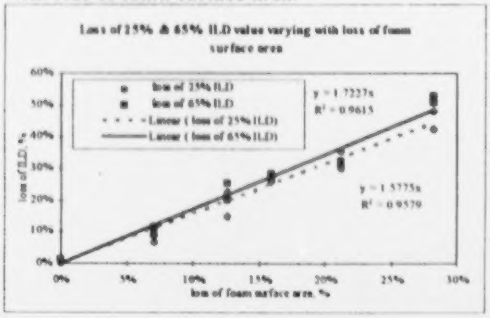


Figure 2. Loss of 25% and 65% ILD value varying with loss of foam surface area.



The % loss of ILD was studied after a period of static degradation. As shown in Fig 3. the loss of the ILD value at day 7, day 30 and day 95 were 24.5%, 32.4% and 45.7% respectively. It showed a sharp decrease in the % loss of ILD during the first 7 days and then further degradation became slower. Similar results were found in the dynamic degradation as shown in Fig 4. The loss of ILD during dynamic degradation at 8000 cycles and 80000 cycles were 30.8% and 43.2% respectively. The analysis of variance suggested that the % loss of foam surface area did not significantly affect the static and dynamic degradation properties at the 0.01 level.

Figure 3. Static degradation - % loss of ILD varying with no. of days of compression.

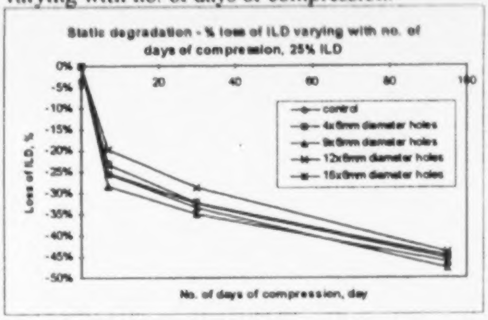
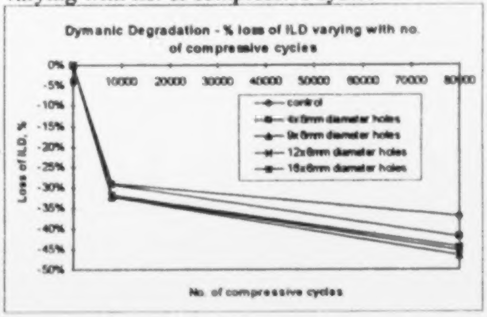


Figure 4. Dynamic degradation - % loss of ILD varying with no. of compressive cycles.



CONCLUSIONS

The results indicated that the percentage loss of ILD was linearly proportional to the percentage loss of foam surface area. During static and dynamic degradation, PU foam underwent significant changes in supporting properties up to 45.7% (after 95 days of static compression) and 43.2% (after 80000 cycles compression) respectively. Hole-drilling did not seem to affect the static and dynamic degradation properties.

REFERENCES

1.Kosiac M, "Etiology of decubitis ulcers", Arch Phys Med Rehabil Vol.42. pp. 18-28, January 1961.

2.Ryan P. Crenshaw, Lars M. Vistnes, "A Decade of Pressure Sore Research: 1977-1987", J. Rehabil Res Dev, Vol. 26 No.1, pp.63-74, Winter 1989.

3.T.E.T.Kang, A.F.T.Mak and H.C.Man, "Modification of the Local Effective Stiffness of Foams for Special Seating - Finite Element Model

BEST COPY AVAILABLE

Analysis.", Proceedings of the Eighth International Conference on Biomedical Engineering. pp 354-456, 1994.
4.Gary M. McFadyen, David L. Stoner, "Polyurethane Foam Wheelchair Cushions: Retention of Supportive Properties." Arch Phys Med Rehabil, pp 234-237, Vol 61, May 1980.
5.P.C. Noble, B. Goode, T. A. Krouskop, and B. Crisp, "The Influence of Environmental Aging upon the Loadbearing Properties of Polyurethane Foams.", J. Rehabil Res Dev, Vol.21 No.2 BPR 10-40 pp 31-38.

ACKNOWLEDGEMENT

This research is supported by the Universities Grant Committee and the Croucher Foundation, Hong Kong.

Address:
Prof. Arthur F.T.Mak
Rehabilitation Engineering Centre
The Hong Kong Polytechnic University
Hung Horn, Kowloon
Hong Kong
(852)-2766-7673
Email: RCAFMAK@HKPUCC.PolyU.Edu.HK

MECHANICAL EFFECTS OF COATINGS ON CUSHIONING FOAMS

S. Leeann Smith, Gong Song, and Beth A. Todd
University of Alabama
Tuscaloosa, AL

ABSTRACT

To reduce the incidence of pressure sores among the disabled, uncoated open-celled foam cushions are often incorporated into wheelchair seating systems. A coated foam is more desirable, particularly in a clinical situation, because it does not absorb fluids and can be cleaned easily. However, care must be taken that the coating does not alter the pressure relieving characteristics of the foam. In this study, changes in the mechanical properties of coated and uncoated cushioning foams were investigated by performing compression tests on four types of foam. The compression tests were performed according to American Society for Testing Materials Standards. The results show that the addition of the coating can significantly change the Modulus of Elasticity and the Support Factor for each material. Therefore, it becomes very important to determine whether the coating will alter the pressure relieving capabilities of the foam prior to coating a foam and to adequately test the coated foam before recommending its use.

BACKGROUND

Decubitus ulcers, or pressure sores, are a serious problem for the disabled and elderly who may be confined to a wheelchair for as many as 12-16 hours per day. A significant contributing factor to the formation of decubitus ulcers is inadequate pressure relief between the wheelchair cushion and the buttocks. To aid in the reduction or prevention of the pressure sores, foam materials must be used which will provide adequate pressure relief between the cushion and the buttocks. Presently, most cushions are made from open-celled, or un-coated, flexible plastic foam. However, these open-celled foams absorb liquid health-care products such as disinfectants, ointments, and rubbing alcohol as well as bodily fluids. A coated foam is desirable, particularly in a clinical situation, because it does not absorb fluids and can be cleaned easily. However, care must be taken not to alter the pressure relieving characteristics of the foam when it is coated.

RESEARCH QUESTION

In this study, the effects of coating on the mechanical properties of cushioning foams were investigated. Therefore, compression tests were performed on four types of foam, both coated and un-coated. The four types of foam are: Fire Resistant (FR) Polyurethane (PU), #6 PU, PU Beige, and Vinyl/Nitrile Copolymer (tradename UL Spongee).

METHOD

The compression tests were performed according to the American Society for Testing Materials Standard ASTM D 3574-86, "Standard Methods of Testing Flexible Cellular Materials-Slab, Bonded, and Molded Urethane Foams (1)," Tests B_1 and B_2. An Instron Universal Testing Machine was used to perform the compression test. Figure 1 shows an illustration of the experimental setup. The foam was supported by a 13 in. x 13 in. aluminum plate with 0.25 in. diameter holes on 0.5 in. centers, which allows the foam to "breathe" during the test. An 8 in. diameter aluminum circular plate was used as an indenter. All of the foam specimens except the UL Spongee were 4 in. thick and 12 in. square. The UL Spongee foam was 1.5 in. thick and 11.75 in. square.

Prior to testing the material, a preflex was performed to insure repeatable results. For Test B_1, the foam was preflexed by compressing it twice to 80% of the thickness at a speed of 1 in/min. The specimen was then allowed to rest 6 ± 1 minutes. After completing the preflex, the foam was compressed to 25% of the thickness at a speed of 2 in/min, then allowed to rest 60 ± 3 seconds while the force drifted. The deflection was then increased to 65% thickness, allowed to rest 60 ± 3 seconds, then decreased back to zero deflection.

For Test B_2, the foam was preflexed by compressing it twice to 75 lbf at a speed of 1 in/min. The specimen was then allowed to rest 6 ± 1 minutes. After completing the preflex, the foam was compressed to 25 lbf at a speed of 2 in/min.

then allowed to rest 60 ± 3 seconds while the force drifted. The force was then increased to 50 lbf, allowed to rest 60 ± 3 seconds, then decreased back to 0 lbf.

The major difference between Tests B_1 and B_2 is the magnitude of the strain. Since the 50 lbf in Test B_2 occurs at a low strain (<12%), the maximum strain (65%) reached in Test B_1 is much greater than the maximum strain reached in Test B_2. For the FR PU and PU Beige foams, the maximum strains reached in Test B_2 were 34% and 23%, respectively, because the foams did not fully recover after the preflex. In other words, there was an initial deformation or residual strain in the material with no load being applied.

During the tests, the Instron Machine plots the Force vs. Deflection curves. The test was repeated 6 times for each specimen. The data from the 6 tests were averaged and used to generate the Force vs. Deflection, Stress vs. Strain, and Modulus of Elasticity vs. Strain curves. The Modulus of Elasticity, E, is the slope of the Stress vs. Strain curve and can be calculated from the linear portion of the curve using Equation (1):

$$E = \Delta\sigma / \Delta\varepsilon \qquad (1)$$

where $\Delta\sigma$ is the change in stress and $\Delta\varepsilon$ is the change in strain (2). As shown in Figure 2, the relationship between stress and strain was linear between 10% strain and 50% strain. The analysis of the nonlinear portion of the curve will be discussed in a future paper.

For Test B_1, the support factor (SF) can be calculated using Equation (2):

$$SF = F \text{ at } 65\% \text{ thickness} / F \text{ at } 25\% \text{ thickness} \qquad (2)$$

where F is the applied force. According to ASTM D 3574-86, "seating foams with low support factors will usually bottom out and give inferior performance" (1).

RESULTS

The Stress vs. Strain curves for Tests B_1 and B_2 are shown in Figures 2 and 3 for the #6 PU Foam and in Figures 4 and 5 for the FR PU Foam, respectively. It can be seen that the Modulus of Elasticity for the #6 PU foam increased by only 20% when a coating was added, but the Modulus for the FR PU foam increased by 810% when a coating was added. In Test B_1 for the FR PU coated foam, the stress remained at zero until the strain reached about 25% because the foam did not fully recover after the preflex. Although the foam did not fully recover after the preflex in Test B_2 for the FR PU foam, the stress did not begin at zero because the first data point was taken at an applied force of 10 lbf.

Table 1 shows the Modulus of Elasticity for Test B_1 for each of the foams. The Moduli were calculated for Test B_1 and Test B_2, but only the results from Test B_2 are shown because the strain is over a wider range. For a single material, the Moduli from the two tests are similar in the linear region of the curve.

The support factors for each of the four foams are shown in Table 2. The SFs for the FR PU and PU Beige foams could not be calculated because the foams did not fully recover after the preflex and had an initial deformation greater than 25%.

DISCUSSION

The addition of the coating changes the Modulus of Elasticity and the Support Factor for each material. As can be seen from the results, a coating can have a significant effect on the material properties of the foam. Therefore, it becomes very important to determine whether the coating will alter the pressure relieving capabilities of the foam prior to coating a foam and to adequately test the coated foam before recommending its use.

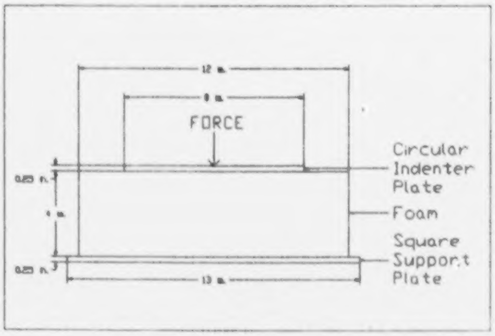


Figure 1. Illustration of experimental setup.

BEST COPY AVAILABLE

Material	Un-coated (psi)	Coated (psi)	Change (%)
#6 PU	2.8	3.4	20
FR PU	1.5	13.6	810
PU Beige	1.9	14.1	660
UL Spongee	19.8	20.8	5

Table 1. Modulus of Elasticity from Test B_1 for the four foam materials.

Material	Un-coated (psi)	Coated (psi)	Change (%)
#6 PU	2.65	2.55	3.72
FR PU	2.12	-	-
PU Beige	2.15	-	-
UL Spongee	5.47	5.32	2.72

Table 2. Support factors for the four foam materials.

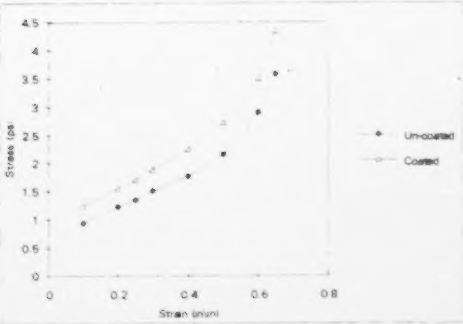


Figure 2. Stress vs. Strain for #6 PU foam. Test B_1.

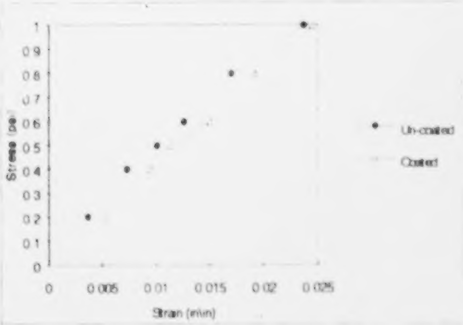


Figure 3. Stress vs. Strain for #6 PU foam. Test B_2.

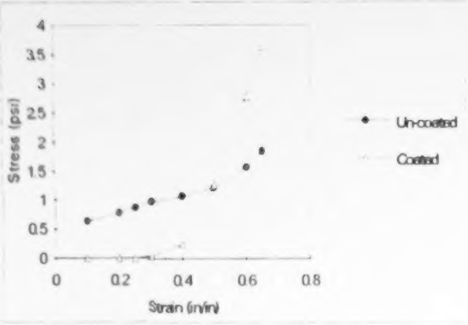


Figure 4. Stress vs. Strain for FR PU foam. Test B_1.

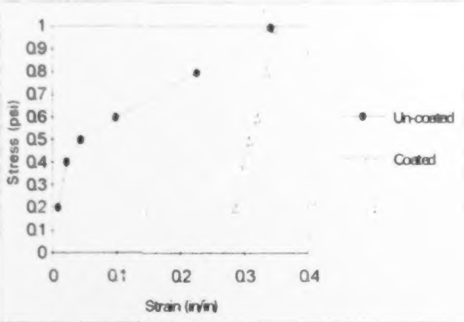


Figure 5. Stress vs. Strain for FR PU foam. Test B_2.

REFERENCES

(1) ASTM D 3574-86, "Standard Methods of Testing Flexible Cellular Materials-Slab, Bonded, and Molded Urethane Foams," 1986.

(2) Beer, Ferdinand P. and E. Russell Johnston, Jr. "Mechanics of Materials," 2nd Ed. McGraw-Hill Inc. N.Y. 1992. pg. 47.

S. Leeann Smith
c/o Dr. Beth A. Todd
Dept. of Engineering Science and Mechanics
Box 870278
University of Alabama
Tuscaloosa, AL 35487-0278
(205) 348-1623
Fax: (205) 348-7240

BEST COPY AVAILABLE

A BIOMECHANICAL APPROACH TO SEAT CUSHION COMPARISON IN WHEELCHAIR USERS

G. Abello[1], M. Ferrarin[1,2], A. Pedotti[1,2]
[1]Centro di Bioingegneria, Fnd. Pro Juventute IRCCS-Politecnico di Milano, Milano, ITALY
[2]Dipartimento di Bioingegneria, Politecnico di Milano, Milano, ITALY

ABSTRACT

In this work the development and application of an evaluation protocol to compare different types of seat cushions has been performed. The aim was to study several parameters (physical measurements, postural parameters, functional parameters, etc.) useful to evaluate the performances of the analysed cushions on healthy subjects and patients with different pathologies of the locomotor system, such as Spinal Cord Injuries or Multiple Sclerosis. Using a Tekscan sensor system the pressures distribution under the buttocks and the seating shape were monitored on different kind of cushions.

BACKGROUND

One of the most important problems for paralysed persons are decubitus ulcers under the buttocks, provided by the forced immobility on wheelchair [6]. Besides patients with lower limb paralisis (like Spinal Cord Injuries or Multiple Sclerosis patients) also elderly and all subjects with severe locomotor problems are involved in prolonged wheelchair seating posture. Many efforts were done to build seat cushions with the aim of improving the pressures distribution and comfort in term of posture, temperature and moisture control. Cushions manufacturers are already seeking for some innovative materials and production processes to build better cushion but up to now no optimal system for all patients have been produced [5]. On sale products are very heterogeneous whether the type of material (foam, gel, air-filled, etc.) or the shapes. It is a common opinion that pressure is one of the parameters that play an important rule in the generation of sores [2]; but up to now different are the hypothesis about the maximum acceptable level of pressure [6]. A good cushion not only have to reduce pressure peaks but also have other important characteristics as postural comfort (for example trunk stability) reduction of temperature and moisture dissipation.

Different studies have been performed in the evaluation of pressure under particular body prominances [3,4] or of pressure distribution under the sitting surface [1], but the used methodologies suffered of one of the following disadvantages: difficulties on large scale application, absence of quantitative parameters for cushion evaluation, absence of postural indeces.

RESEARCH QUESTIONS

Looking at the big number of different type of on sale cushion, it's clear the need of an evaluation protocol with the aim of comparing some significant acquired parameters on wheelchair users. Goal of this study is to develop and to validate a procedure based on quantitative parameters to compare different seat cushions in order to find the best one for the single patient characteristics.

METHODOLOGY

The evaluation procedure is intended to be applied on different group of subjects: healthy subject as control, patients with Multiple Sclerosis, patients with Spinal Cord Injury and elderly wheelchair users. The aim of choosing a so heterogeneous group of subjects is to evaluate the cushion in different type of pathologies. In this study four types of cushions are considered: the first (type A) is formed by gel-filled rubber balloons under the buttocks and foam filled ballons under the thighs with a foam base; the second (type B) is formed by gel-filled rubber balloons with a foam base; the third (type C) is a contoured firm foam base covered by a gel pad and the last (type D) is composed by rows of air-filled rubber balloons connected by narrow air channels in a flat rubber base. The first two types are prototype cushions while the third and the fourth are on sale cushions. A standard wheelchair (Sunrise Medical, Quicker Model) is used for the pressure tests; adjusting the footrest in order to have a 90° degrees knee angle. No armrests are used so that load is completely supported by the seat cushion and the footrest in order to avoid uncontrollable modification on pressure provided by upper limb weightbearing.

The instrumentation (Tekscan sensor system) is an integrated device for measuring interface pressure that consists of a thin matrix (42 rows and 48 columns) of pressure sensors (1 cm^2 of area each one) put into a pad and a personal computer with a particular software that allows to store and to represent all collected data.

The sensors pad is put on the seat cushion and the subject is asked to seat comfortable in the wheelchair for a total time of 20 min. during which an acquisition of pressure distribution (10 Hz sampling rate, 2 sec duration time) is performed every 5 min in order to see possible modifications during time.

From the pressure distribution 3D diagram a first analysis is performed on the type of seating posture (ischial, sacral, etc.) and the level of uniformity in the distribution (i.e. presence of critical areas with peak of pressure).

Some numerical parameters are then computed like the maximum peaks and mean pressures in particular areas under the buttocks (ischial tuberosities, great trochanters, sacrum and coccyx). Postural parameters as the asymmetry of load distribution, position of pressure centre respect anatomical reference system and seat contour characteristics [1] are then computed. The reference system is defined by the segment linking the ischial tuberosities and its medial axis. A dedicated software able to compute automatically all these parameters has been developed.

A subjective evaluation (comfort, stability, etc.) taken from a dedicated questionnaire is considered too and its results are correlated with the measured parameters.

RESULTS

Preliminary acquisitions have been performed on two healthy subjects in order to validate the acquisition procedure. From these acquisition the following results have been obtained showing interesting differences among the several type of cushions.

In fig.1 the tridimensional representation of pressure distribution of an acquisition using a type B cushion is shown: the maximal pressure peaks under the ischial tuberosities are evident. For the same trial in fig.2 the contour characteristics in term of isobar lines are shown together with the anatomical reference system of the seating. The black circle visualize the centre of pressures, useful to quantify the postural assimetry through its distance from the reference system axis.

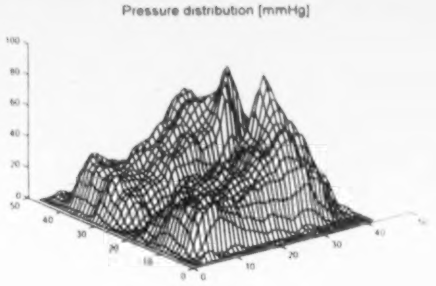


Figure 1

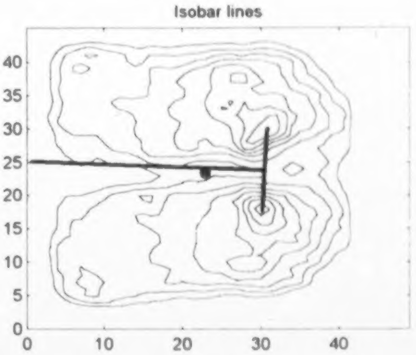


Figure 2

Fig. 3 shows an acquisition made on the same subject using a cushion of type C. In this case the maximal peaks of pressure are under the great trochanters showing a different type of seating posure.

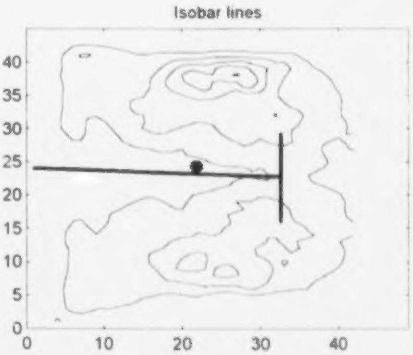


Figure 3

Computed parameter on acquired datas of two healthy subjects are shown in table1. "Max" R and L indicate the maximal peak pressures found

respectively on the right and the left side of the body. "3x3" R and L are the mean pressures of a 9 cm² area centred aroud the maximal value (Max R and L). "Std" is the standard deviation of pressure values acquired by all sensors, representing the variability around the mean value, useful to quantify the presence of uneven distribution. "Surf" indicates the area under the contact surface of cushion and "local" specifies the localisation of the maximal pressure peack.
These datas refer to the acquisition performed after 5 min of seating.

TABLE I

		Max R	Max L	3x3 R	3x3 L	Std	Surf.	Local.
Type A	Sub. 1	81	69	60	51	18	1853	Ischial
	Sub. 2	92	97	65	66	18	1862	Ischial
Type B	Sub. 1	74	62	64	50	18	1840	Ischial
	Sub. 2	84	93	63	64	19	1864	Ischial
Type C	Sub. 1	120	82	73	59	21	1875	Troc.
	Sub. 2	104	66	67	53	19	1866	Troc.
Type D	Sub. 1	103	92	78	66	24	1814	Ischial
	Sub. 2	86	96	60	77	24	1844	Ischial

DISCUSSION

Looking at table 1 the following considerations on the comparison of the four type of cushions can be deduced.
Type A and B have the same contruction characteristics (rubber ballons with a base of foam) but are done with different materials (one have all ballons filled with gel while in the other it is only under the buttocks). Datas indicate that gel all over the surface decrease maximum peacks of pressure in these two subjects while both present the same type of posture (ischial seat).
Also type D cushion show an ischial seat but with a smaller contact area than the first two cushion. A bigger "std" is present too indicating a lower level of pressure distribution uniformity.
Type C cushion shows a different seating posture characterized by a maximum load on great trochanters in both subjects. A high level of asymmetry between right and left side can be recognized too.
Concerning trend in time a general decrease in pressure values was found even if with some exception.
Next step is to repeat these acquisitions on a consistent number of patients.
In the future a modified protocol will be developed to study particular parameters that allow to change some cushion properties (thickness, gel distribution, gel amount, etc.) in order to adapt it to the single patient characteristics. The aim is to change in the best way the shape of the cushion to reduce pressure peaks and to improve patient comfort.

REFERENCES

[1] Springle S., Schuch J., "Using seat contour measurements during seating: evaluations of individuals with SCI". Assist Technol 1993; 5:24-35.

[2] Shaw G., "Seat cushion comparison for nursing home wheelchair users". Assist Technol 1993; 5:92-105.

[3] Della Valle I., Battisti N., Puglisi C., Di Gioia S., "Cuscini antidecubito: la riduzione di pressione quale indicatore reale della loro efficacia". Giorn Ital Med Riab 1992; 4(VI):369-374.

[4] Patterson R., Fisher S., "Sitting pressure-time patterns in patients with quadriplegia". Arch Phys Med Rehabil 1986; 67:812-814.

[5] Garber S.L., Krouskop T.A.., "Wheelchair cushion modification and its effect on pressure". Arch Phys Med Rehabil 1984;65:579-583.

[6] Ferguson Pell M.W., "Seat cushion selection", J Rehab Res & Dev, Clinical Supplement n.2, March 1990; 49-73.

ACKNOWLEDGEMENTS

This work is supported by a grant from Royal Medica S.r.l., Pozzo Leone, Vicenza, Italy

Giuseppe Abello
Centro di Bioingegneria, Fnd. Pro Juventute Don Gnocchi
Via Gozzadini, 7
20148 Milano - Italy
(39) - 2 - 40308305

BEST COPY AVAILABLE

RELIABILITY OF CONTOURS OF POSITIVE MOLDS FOLLOWING SEATING SIMULATION

Maria A. Toney, M.S., P.T., Irene McEwen, Ph.D., P.T., David Thompson, M.S., P.T., Donald Parker, Ph.D.
Oklahoma Assistive Technology Center
University of Oklahoma Health Sciences Center, Dept. of Physical Therapy
Oklahoma City, OK

ABSTRACT

The purpose of this study was to determine the magnitude of variability that occurred between two different casts made for the same individual during two seating simulation assessments. Twenty individuals with developmental disabilities (mean chronological age = 9.9 years) participated in two separate simulation assessments. The contours of the molds were analyzed for differences in contour depth. Results indicated that the protocol used in this study was effective in reproducing the contours for 17 out of 19 individuals with overall variability less than one inch.

BACKGROUND

Individuals with severe cerebral palsy and other neuromotor impairments often have neuromusculoskeletal problems that affect their performance. These problems, which may include skeletal deformities, muscle contractures, and inadequate balance and control of muscle groups, lead to an inability or difficulty in producing movement necessary to perform functional skills.[1-5] Physical therapists are often involved in recommending assistive positioning equipment, including wheelchairs, for these individuals to prevent or decrease the influence of neuromusculoskeletal problems.[1,5,6] Positioning in wheelchairs is especially important, as independent sitting may be limited by neuro-musculoskeletal problems, requiring specialized seating to provide postural support, and increased comfort and function.[1-5]

To achieve optimal alignment in assistive seating equipment, guidelines have been proposed by several authors.[3,5-7] One important consideration is the type of seating surface. Seating systems can have either planar or contour surfaces or a combination of both. A contoured surface is curved, providing closer body contact and support. Contoured systems provide improved pressure distribution, posterior and lateral support, and still allow for some growth and active movement.[6,7] Although authors have recommended the use of contoured systems, especially when positioning individuals with severe physical disabilities, controversy still exists regarding the use of planar versus contoured seating systems.[3,5-7] Clinically, planar systems are still frequently recommended because they are standard on most mobility bases and can be ordered from the manufacturers. Also, some therapists believe that structurally fixed deformities can be corrected or changed and criticize contour systems for conforming to existing deformities and not providing for more normal alignment.[3,6,7]

Professionals specializing in adaptive seating advocate the use of contoured seating systems for many individuals.[6,7] Different types of contoured systems have emerged with recent advancement in the field of assistive positioning. One type of contoured system is Foam-In-Place Seating (FIPS). FIPS are fabricated by either pouring a liquid chemical mixture into a plastic bag positioned around the individual's body or into a prepared cast. FIPS have been used clinically as a method to fabricate relatively inexpensive custom-contoured seating.[7] One fabrication process, utilizing FIPS liquid Sunmate ingredients, requires a therapist to hold an individual in proper alignment while the foam rises and hardens, therefore achieving optimal alignment is in question. However, when a seating simulator is used, optimal position is determined prior to fabrication of the custom-contoured insert.

With the use of a seating simulator, optimal positioning is comprehensively assessed prior to fabricating or ordering an individualized seating insert. Simulation is a process by which therapists can assess an individual in a sitting position while changing various angles, depths, and tilts-in-space before determining optimal position for an individual. Simulators come with both planar and contoured seating surfaces. The contoured surfaces are molding bags filled with plastic pellets attached to vacuum pumps which air to flow into and out of the bags as the pellets are positioned around the individual. When the optimal position is achieved, the air is vacuumed out of the molding bags, solidifying the surface for casting. Plaster casting material is then used to make a positive cast, replicating the contours of the simulator mold. After the cast has dried, the liquid foam ingredients are poured into the prepared cast for fabrication of the contoured foam inserts.

With simulation, therapists can determine position for sitting tolerance, weight distribution, and functional capabilities. It allows the individual time in the device prior to fabrication so the therapist can evaluate neuromotor and behavioral responses to the change in position.[6,7] With the use of simulation, clinicians believe that more consistent optimal positioning can be achieved;[6] however, there is no research to support this clinical belief. The purpose of this study was, therefore, to determine whether or not two casts fabricated during separate simulation assessments for the same individual yielded consistent contours.

RESEARCH QUESTION

The following research question is addressed by this study: Following two seating simulation assessments on the same individual, what is the magnitude of differences between the contours of the two casts?

METHODS

Twenty individuals with developmental disabilities participated in the study. Participants' ages ranged from 2 years to 46 years with a mean of 9.9 years. All participants were positioned on a seating simulator, adjusted to provide optimal postural support according to guidelines suggested by Bergen et al.[6] Utilizing the simulator, optimal body position, seat-to-back angle, and tilt-in-space were determined by the investigator. Written procedures to determine optimal positioning were followed.

Each participant was seen twice. Nine of the participants were seen one week apart and the remaining eleven were seen in the morning and afternoon of the same day. The location of the sessions was consistent for each participant. Each assessment began with a mat/handling evaluation, and was followed by a simulator assessment. The simulator molding system was used to determine and hold the participants' optimal position. The firm impression was used to form a positive mold which was cast according to the protocol.

After the cast dried, it was sent to Akron-Cleveland Home Medical Services, for measurement of its contours. The contours were measured using the Signature 2000 contour measurement system. The negative side of the cast was measured for better accuracy. Before placing the casts on the Sensing Array, they were levelled and stabilized, assuring no movement during the sensing phase. After the sensing was complete, a representative from Akron-Cleveland Home Medical randomly chose 32 points per line for each participant and printed out the 32 points which represented the line chosen. The 32 points were printed and labeled according to participant and line number, and returned to the participating facility. The same lines were measured on both casts for each participant. Keeping the line numbers constant ensured that the X (contour width) and Y (sitting depth) measurements were consistent for Cast 1 and Cast 2, leaving the Z (contour depth) as the only source of variability.

The contour data (Z measurement in inches) from 19 participants' casts were analyzed for variability. Cast one for Participant #9 was lost in the mail and data were not received, excluding them from the study. Occasionally, lines were deleted from each cast because they represented not contours of the cast, but areas at the back of the cast beyond the participant's body.

Using SAS' Univariate procedure, summary statistics were used to describe differences and absolute differences computed for the corresponding points from Cast 1 and Cast 2 for the entire group of participants. Absolute difference scores were utilized for analysis as the purpose of the study was to estimate the magnitude of variability that could be expected between casts, and not to determine if significant differences occurred between the two.

Following the group analysis which included all the participants' data, outlying scores were identified by participant and by line. This provided information on the exact location of extreme differences, located any patterns consistent between all participants, and revealed more clinically relevant information. Group data were further sorted by participant and by participant and line to specifically look at the patterns and location of the differences.

RESULTS

The mean absolute difference in contour depth for all participants was 0.66 inch with a standard deviation of .8690, the median difference was 0.3889. With such a difference between the mean and median absolute differences, it was evident that the distribution was skewed to the right toward higher differences.

Outliers were identified as absolute differences greater than 1.0 inch . Of the 4,863 absolute differences, 925 (19%) were greater than 1.0 inch. Participants 1, 4, 11, and 20 accounted for 40% of the absolute differences greater than 1.0 inch. Twenty-four percent of the absolute differences greater than 1.0 inch occurred on Line 1. The last line on various casts accounted for an additional 17% of the absolute differences greater than 1.0 inch. Data sorted by participant revealed the mean absolute differences were less than 1.0 inch for all participants, except #1 and #4. Data sorted by participant and by line revealed that 132 (88%) of the total 152 lines analyzed had mean absolute differences less than 1.0 inch.

DISCUSSION

The descriptive statistics calculated for the entire group provided overall information, and showed that variability, which was expected, did exist between Cast 1 and Cast 2 for all participants; however, more specific information regarding the exact location of the differences determined the sources of variability.

When outlying or extreme absolute differences were analyzed by participant and by line, some patterns emerged as to their location. Participants 1 and 4, and the first and last lines of all participants surfaced as consistent sources of extreme variability. Investigator's reports indicated that both participants were seen one week apart and had been sick at the time of their second session. Variability on Line 1 and the last line is likely to be due to how far and the angle at which the casting tape was brought over the edge of the mold.

When absolute difference scores by participant were analyzed, no new findings occurred. Participant 1 and 4 continued to represent a primary source of variability. However, when absolute differences were sorted by participant and by line, an unexpected finding occurred which varied from earlier findings. Participant 4's cast surfaced as having problems only with the last 2 lines. These two lines skewed the distribution and raised the mean absolute difference above 1.0 inch.

No research is currently available identifying how much variability can exist without changing the actual contours to a degree to which they would cause problems for the user. However, Shields and Cook found that lumbar support thickness greater than one inch resulted in a significant change in the highest seated buttock pressures. They also found that a 1.0 inch thick lumbar support did not cause a significant change in the highest seated buttock pressures.[8] Therefore, investigators determined 1.0 inch to be the limitation for excessive variability.

This study combined the use of seating simulation and a protocol used by the participating facility to determine optimal positioning for an individual with a disability. Use of both simulation and the protocol are supported by current literature.[6,7] By combining them, this study evaluated the clinical belief that simulation allows clinicians to be more consistent in determining optimal positioning and fabricating custom-contoured seat cushion by analyzing if the contours achieved during two separate simulation assessment were the same. This study took a step toward supporting this clinical belief. The information on contour replicability provided by this study is another step toward ensuring the procedures clinicians use for determining optimal positioning and fabricating custom-contour cushions are procedurally sound.[9]

REFERENCES

1. Presperin JJ. Seating and mobility evaluation during rehabilitation. *Rehab Management.* April/May 1989; 53-57.
2. Fulford GS, Cairns TP, Sloan Y. Sitting problems of children with cerebral palsy. *Dev Med Child Neurol.* 1982;24:48-53.
3. Mulcahy CM, Pountney, TE, Nelham RL, et al. Adaptive seating for the motor handicapped: problems, a solution, assessment and prescription. *Physiotherapy.* 1988;74:531-536.
4. Medhat MA, Redford JB. Experience of a seating clinic. *Internat Orthop.* 1984;9:279-285.
5. McEwen IR, Lloyd LL. Positioning students with cerebral palsy to use augmentative and alternative communication. *Language, Speech, and Hearing Services in Schools.* 1990;21:15-21.
6. Bergen AF, Presperin J, Tallman T. *Positioning for Function: wheelchair and Other Assistive Technologies.* Valhalla, NY: Valhalla Rehabilitation Publications Ltd; 1990.
7. Presperin J. Seating systems: The therapist and rehabilitation engineering team. *Phys Occup Ther Pediatr.* 1990; 10(2):11-45.
8. Shields RK, Cook TM. Lumbar support thickness: effect on seated buttock pressure in individuals with and without spinal cord injury. *Phys Ther.* 1992;72(3):218-226.
9. Sprigle S, Schuch JZ. Using seat contour measurements during seating evaluations of individuals with SCI. *Assistive Technology.* 1993;5:23-35.

ACKNOWLEDGEMENTS

This research was supported by the U.S. Department of Education Preparation of Related Services training grant, #H029F00056, and the 1993 Oklahoma Health Sciences Center Summer Academy for Health Sciences Professions, Oklahoma State Regent's Higher Education. A special thanks to Dynamic Systems, Inc. who provided a gracious donation. And finally, a sincere thanks to the staff at the Oklahoma Assistive Technology Center who assisted throughout the duration of the study.

Maria Toney, MS, PT
Oklahoma Assistive Technology Center
University of Oklahoma Health Sciences Center
Division of Rehabilitation Sciences
1122 NE 13th, Rm WB-400
Oklahoma City, OK 73117 U.S.A
(405) 271-3625; FAX (405) 271-1707

A Reusable Mold For Custom Contour Cushion Manufacturing

Narayan L. Gehlot, MS, David M. Brienza, Ph.D. and Michael Silverman†
University of Pittsburgh
† Pin Dot Products

Abstract

An improved custom contoured cushion (CCC) manufacturing system is investigated. In this paper, design alternatives for a computer-controlled surface to replace the permanent mold in the custom contoured cushion manufacturing process is reported. The system is potentially more cost effective and efficient than current molding systems. Magnetic breaking (EMB) of individual control components was conceived and key system components were designed, fabricated and tested. Physical models of a three-dimensional control rod surface were fabricated for testing of flexible materials and composite structures that might form the three-dimensional surface of the mold cavity. The system's electrical, mechanical, throughput and cost specifications are reported. Contours up to 20"x20" with a depth of 6.2" are possible with this system. EMB speed versus positioning errors is presented which sets upper limit on throughput in manufacturing.

Background

Custom contoured cushions are successfully used by people with disabilities for both "pressure relief" and "postural control" applications; however, more widespread use is hindered by the high cost and complexity of fabrication. The most common manufacturing techniques used for custom contoured foam cushions are (1) direct carving of foam, (2) carving of a mold then vacuum forming, and (3) manual mold making then vacuum forming. The aims of the device described, the so called NetShape device, are to improve on the current fabrication processes by increasing efficiency, decreasing waste, reducing labor cost, allowing for faster delivery, improving means of quality assurance and reducing manufacturing facility requirements.

Method

Cushion Forming Process: The NetShape device is best described as a shapable semi-rigid net or mesh surface for which the position—or height—of each woven net intersection is numerically controlled. Once shaped, the surface is used as a mold or die shape for the fabrication of a foam support surface. The device configuration can be described as having a master device which is computer controlled to create three dimensional contours by locking control rods at each software determined control point. The initial locking of the control rods is done by the activation of an electromagnet associated with each control rod as that control rod moves through the software defined control point. A secondary mechanical locking mechanism is used to apply a greater locking force to the collective control rod structures with sufficient force to maintain the three-dimensional contour accuracy during the transfer of this contour to a mechanical slave device.

The mechanical slave device is constructed with a similar geometry to the master NetShape device but incorporates control rods of increased structural strength and a mechanical locking mechanism that applies sufficient locking force to the slave control rods to maintain their position under the forces exerted by the various manufacturing operations necessary to construct the mold surface and contain the expansion forces of the chemical foam.

The separation of the NetShape manufacturing technology into a master and separate slave configuration has several advantages over a single device. The complex heavy and bulky electromechanical mechanism of the master NetShape device is removed from the cushion fabrication process so that it is not subject to potentially lengthy and expensive maintenance that would be associated with a failure of the contoured surface to contain the chemical foam. The slave device can be designed to be mechanically more compact and lighter weight than the master device. This will facilitate handling of the device by the production employees and separate the activities of production under automation control from those activities under employee discretion and control.

The slave device is an order of magnitude less expensive than the master device. One master device should generate contour information for the slave device at ten-minute intervals. The use of three or four slave devices with one master could result in 100% duty cycle for the master device and generate a six-fold increase in production over the current carving approach.

An adjustable frame, sized to match the outer dimension of the cushion will be placed about the contoured mesh of the slave device. The top opening of the airtight box will then be sealed with an elastic membrane. A vacuum will be used to cause the membrane to conform to the cushion shape of the adjustable frame and contoured mesh. The space behind the membrane will be back filled with foam to form the cushion.

tested to evaluate the overall feasibility of the approach. This feasibility investigation included determining the magnet configuration, designing the driving circuit for the magnet array, designing and evaluating the positioning rod assembly, determining any limitations on the pitch caused by the magnet assembly, determining the power requirements of the magnets and driving circuit, designing the locking mechanism, and testing the flexible membrane materials. Alternate approaches that required many servo motors or expensive robotic equipment were ruled out. The required pitch—or spacing—of the positioning elements for faithful reproduction of cushion contours depends primarily on the ability of the wire mesh to form a sufficiently smooth surface for the vacuum forming or foam expansion processes. Based on the work performed experimenting with wire mesh and membrane materials for the vacuum-formable surface of the slave device, it was determined that an element pitch of 0.75" used in with layered flexible membranes and without a wire mesh would be sufficient.

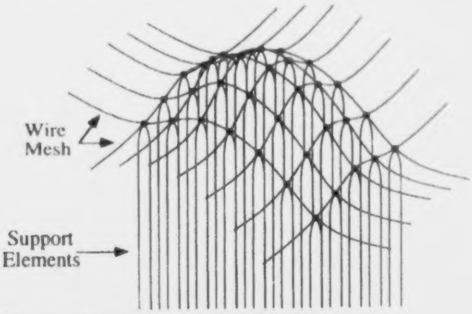


Fig. 3 - Wire mesh surface-NetShape

Optimum Magnet configuration: The first design issue to be resolved was the shape of the magnet. Standard shapes considered were U-shaped, C-shaped and cylindrical. The criteria are efficiency, cross-talk between elements, mounting convenience size and the magnet core material. Theoretical analysis [1] and experimentation determined that a U-shaped magnet made with an iron core was the best configuration. Iron was chosen over a more efficient non-conducting core such as ferrite [2] after the possibility of using an AC current to drive the coil was rejected. While ferrite is more efficient and allows AC excitation currents, the iron provides design flexibility because it is more easily machined. The U-shaped core mounted on end provides a closed path for flux conductance and minimizes required space. Cylindrical cores [3] are less efficient due to the absence of a closed path and require extraordinary shielding to eliminate cross-talk with adjacent elements. The C-shape core is more difficult to mount than the U-shaped core, takes up more space because it must be mounted flat and offers no advantages over the U-shaped core. The U-shaped core can be mounted on end while providing a flat mounting surface without interference from the coils which are located around the straight upright portion of the core. The force generated by the U-shaped magnet is a function of the number of coil turns, the core material and size, and the current flowing in the coils. It was determined that a current of 69 mA is required to stop and hold the 12" x 1/4" solid mild steel rod used in the positioning mechanism. U-shaped magnet core specifications are as follows: Dimensions 0.75 x 0.375 x 0.125, Material C1018 low carbon steel, Coil wire AWG 34 (insulated copper) and Number of turns (N) 1111.

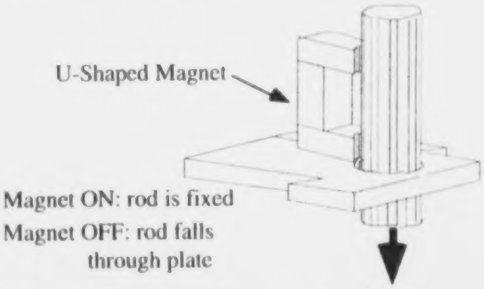


Fig. 4 – U-Shaped magnet core and rod motion

Driving circuit: The coil driving circuit used during the model evaluation is shown in Fig. 5. For the model, UDN2543B [4] quad power drivers were used to activate the magnets. In the full scale system to be constructed, UCN5816 [4] ICs will be used. The power requirement was determined to be 0.406W per element in the positioning assembly which is equal to ~296W total based on a 20"x20" surface with 0.75" spacing between 729 positioning elements. The simultaneous use of 729 electromagnetic brakes may induce or cause difficulties not evident in the limited models fabricated and tested.

Locking mechanism: A mechanical lock was designed and tested, it consisted of three plates with clearance holes for the control rods lined with high friction elastomer. Mechanical translation of the middle plate relative to the other two results in a clamping action. An analogous locking device can be used to lock the contour transferred to the slave device.

Contour depth: The maximum depth of typical cushions currently used for pressure relief applications is generally less than 3.0 in. In the current design it is possible to have 6.2" of contour in a 7.0" deep cushion, which should allow for the production of commercial seat and back systems that are clinically effective.

Match point positioning/cycle time: A key feature of the positioning assembly is the ability to set and hold a large number of positioning rods quickly and accurately while using inexpensive and reliable machinery. The purpose of the test described in this section was to evaluate the accuracy of the system. The factor effecting the ability of the system to accurately position the positioning rods is the delay between the time when a magnet is commanded to grab a rod and the time when the rod stops and is held in place. This delay is a function of the force generated by the magnet, the inductance of the windings and the time required by the driving IC to generate current through the windings. For the experimental activity, the guide plate was manually operated. Such manual operation could result in inconsistent guide plate speeds. Also, since the time delay depends on, among other things, the velocity dependent momentum of the rods, it was not expected that the distance traveled during the delay would be linearly related to the velocity.

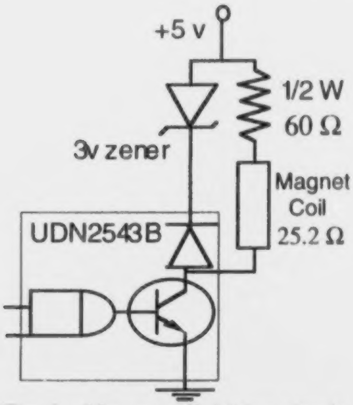


Fig. 5 – Magnet coil driving circuit

Results and Discussion

A test setup consisting of the model positioning assembly, Macintosh Quadra 800 microcomputer, National Instruments MIO16 multipurpose I/O card and Labview data acquisition and control software was used to evaluate the model positioning assembly design concept. A test program was developed that assisted in determining the magnet's ability to pull in and hold a moving positioning rod. The positioning rod was set into motion by hand just before latching the digital output line connected to the coil drive IC. The distance traveled by the rod between the time it was commanded to stop and when it actually stopped was measured using a linear potentiometer coupled to the guide plate which lowered the positioning rods. The results for speeds ranging from 0 to 6 inches per second are shown in Fig. 6. Based on the results to this test, it is estimated that the positioning process will require less than 10 seconds for an average 4" contour with an accuracy exceeding 0.02" (0.508 mm). This estimate accounts for the extra time required when many rods are held at nearly the same level and assumes the guide plate will be moved at a rate slower than 1" per sec.

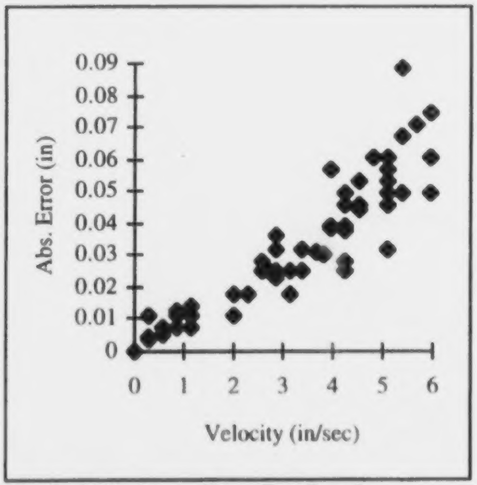


Fig. 6 - Velocity vs. Error Test Result

The NetShape machine cost is estimated to be less than $20,000. The work completed suggests that NetShape throughput is potentially twice that of current NC cushion carving systems. When compared to traditional molding processes, the operating complexity of the proposed NetShape technology is less, because the design decisions for all features of the cushion products are incorporated into the design process using software.

References

[1] C.R. Paul & A. Nasar, *Introduction to Electromagnetic Fields*, McGraw Hills, 1982
[2] Fair Rite, *Fair-Rite Soft Ferrite*, 12th Edition, 1993
[3] B. Grob: *Basic Electronics*, McGraw Hills, 1977
[4] Allegro Micro Systems, *Data Book AMS 501*, 1993

Acknowledgments

This research is support by the National Institutes of Health, National Institute of Child Health and Human Development, National Center for Medical Rehabilitation Research. Grant #1 R43 HD30625-01.

US Patent pending, Serial Number 08/189,490

Narayan Gehlot, MSEE, Ph.D. (candidate) EE
University of Pittsburgh, School of Engineering
School of Health & Rehabilitation Sciences
915 William Pitt Way, Pittsburgh, PA 15238
Phone: 412-826-3138, Fax: 412-826-3143

WHEELCHAIR CRASH STRUCTURAL COMPUTER MODEL

G. S. Dupuis, W. D. Pilkey, J. G. Thacker, and W. Kang
Transportation REC, University of Virginia
Charlottesville, VA 22903, U.S.A.

Abstract

A dynamic, nonlinear, computer model is being developed to simulate the crash effects on a wheelchair-occupant system secured to the floor of a vehicle. The LS-DYNA3D software is being used to simulate an Invacare Ranger II power wheelchair with a seated Hybrid III dummy.

Introduction

The increasing need of mobility for the physically challenged results in a significant driver and passenger population who sit in wheelchairs while riding in vans and buses. The wheelchair tiedowns and occupant restraint systems can reduce the possibility of injury by preventing the wheelchair and occupant from moving and hitting the vehicle interior during a crash. To develop a wheelchair tiedown and occupant restraint system, the dynamic responses (restraint forces, accelerations, and excursions) of the wheelchair-occupant system under crash loadings need to be analyzed. Computer simulations which model the wheelchair with rigid lumped masses have been used to study these dynamic responses[1]. However, these models failed to account for the large scale deformations which occur in the wheelchair. The nonlinear finite element approach is able to model these deformations.

Wheelchair-Occupant Model

A computer model is being developed to simulate a wheelchair-occupant system tied down to a vehicle under the impact loadings of a 30 mph crash. Figure 1 shows the complete wheelchair occupant model. The LS-DYNA3D finite element simulation package[2] is being used to simulate the system. The program is an explicit, three dimensional, finite element code for analyzing the large deformation dynamic response of inelastic solids and structures. Spatial discretization in this model is achieved with eight node solid elements, two node beam elements, and four node shell elements.

The simulation models an Invacare Ranger II power wheelchair. Figure 2 shows the computer model of the wheelchair. The steel frame of the wheelchair is modeled with 206 tubular two node beam elements. Figure 3 shows the computer model of the wheelchair frame. The steel is simulated with a piecewise linear isotropic plasticity model for the nonlinear crash response of the frame. The elastic response of the material is represented with a linear relationship. A series of data points is used to represent the plastic nonlinear part of the material response. The joints which connect the crossbars to the two side frames are modeled with cylindrical joints. The seat tubes are also connected to the side frames with sliding joints located at the backrest support tubes and near the front of the seat. These joints are represented with finite element sliding joints. Each of the two forks which connect the front wheel axles to the frame is modeled with 12 four node shell elements which have the same material model used for the steel tubular beam elements. Each footrest is modeled with 4 four node steel plate elements. The seat and the backrest are modeled with 30 and 42 four node shell elements, respectively. The material of which the seat and backrest are composed is modeled with a fabric membrane material in which there are no compression stresses. Each of the 4 wheels is connected to the frame with axles that are modeled with tubular beam elements. Each wheel is modeled with 24 solid elements: 12 six node solid elements which model the rim and 12 eight node solid elements which model the tire. The batteries, the motors, and the various components of the wheelchair are modeled with point masses and moments of inertia.

The dummy model is part of the software package. This model is a multi-rigid body representation of the HYBRID III dummy (Fig. 4). It is a 50th percentile male in which the 15 separate rigid ellipsoids are connected by 14 spherical joints and 84 springs. LS-DYNA3D has a three dimensional contact-impact algorithm which is used to model contact between the dummy and itself, the seat belts, and the wheelchair.

The wheelchair tiedowns and the occupant restraints are modeled with LS-DYNA3D's seat belt elements which only act in tension. Load curves were input to represent the nonlinear webbing force-elongation relationship.

Wheelchair Crash Structural ComputerModel

Uses of Model

This model is being used to predict the dynamic response of the wheelchair-occupant system in a sled test. It predicts displacements, stresses, and strains throughout the wheelchair frame and locates the points at which failure will most likely occur. It indicates the forces acting through the seat belts and the accelerations and forces acting on the dummy. This finite element method could be used to find ways to make this particular wheelchair design more crashworthy as well as to evaluate other wheelchair designs for transportation.

References

1. Pilkey, W. D., et. al.., "Crash Response of Wheelchair-Occupant Systems in Transport", Proceedings of the RESNA '94, June 17-22, 1994, Tennessee, pp61-63.

2. Hallquist, J. O., et al., LS-DYNA3D User's Manual, Beta Version: LS-DYNA3D 930, Livermore Software Technology Corporation, 1993.

Acknowledgement

This research was sponsored in part by the National Institute for Disability and Rehabilitation Research (NIDRR).

G. S. Dupuis, Graduate Student
Department of Mechanical Engineering
University of Virginia
Charlottesville, VA 22903
Tel. (804) 924 - 3291
E-mail: gsd7m@Virginia.edu

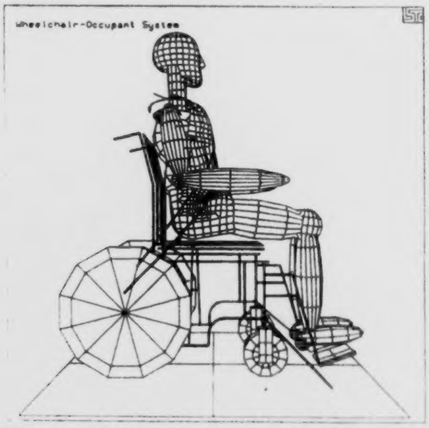


Fig. 1. Wheelchair-occupant model

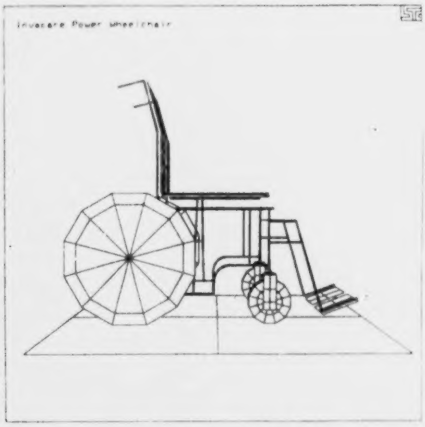


Fig. 2. Wheelchair model

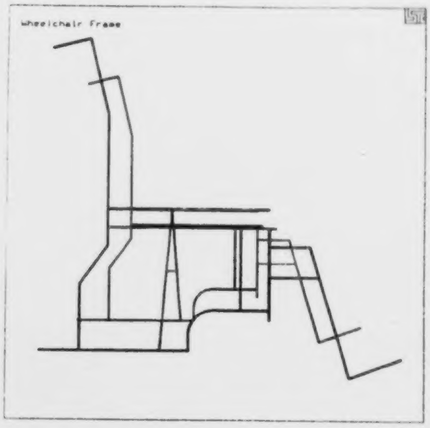


Fig. 3. Wheelchair frame

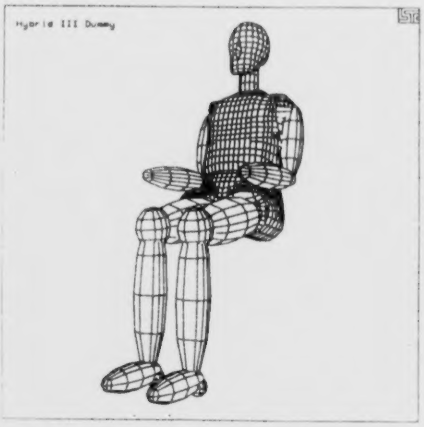


Fig. 4. Hybrid III dummy model

CRASH RESPONSE OF WHEELCHAIR OCCUPANTS WITH DIFFERENT SITTING POSTURES IN TRANSPORT

Weize Kang, Greg Shaw, Walter D. Pilkey, and John G. Thacker
Transportation REC, University of Virginia
Charlottesville, VA, U.S.A.

ABSTRACT

The crash responses of an occupant, who sits in a wheelchair in different seating postures while riding in a vehicle, are simulated using a computer model developed based on inter-laboratory sled crash tests on wheelchair-occupant systems. Recommendations regarding the safe use of the wheelchair when used by the occupants who require sitting postures other than the erect position are presented.

INTRODUCTION

More and more disabled individuals ride vehicles while sitting in mobility aides such as wheelchairs. Currently, efforts have been given to investigations of the crashworthiness of wheelchair tiedowns and occupant restraint systems (WTORS) [1, 2]. A significant number of people who ride vans or buses while sitting in the mobility aids may still be injured or killed in the event of a collision even if approved WTORS are used because present WTORS and safety recommendations regarding their use have been developed primarily for mobility riders who sit erect in a wheelchair. Little research has been conducted for the crashworthiness of the mobility aides when used by the people who require alternative sitting postures such as back recline, back and seat tilt, or upper torso recline left or right.

A computer model has been developed to simulate a wheelchair-occupant system tied down to a vehicle under impact loadings of a crash. The DYNAMAN simulation package (a version of ATB, Articulated Total Body Model) has been used to simulate the wheelchair-occupant system. The occupant model is a 50th percentile male Hybrid III dummy. This model has been validated extensively by the interlaboratory sled tests. It agrees well with these test results, and thus can be used to predict the crash response of a wheelchair-occupant system [2].

The crash response of an occupant (Hybrid III dummy) sitting in a wheelchair with four different sitting postures have been studied using the model. The accelerations and displacements of the dummy head and chest, the dummy loads on the wheelchair, the forces in the restraint system, and the acceleration of the wheelchair, are calculated and compared with the response in the erect sitting posture. Preliminary recommendations regarding the safety use of the mobility aides are suggested.

MODEL SETUP

Figure 1 shows four different sitting postures of an occupant in a wheelchair. The first posture is an erect position, in which the wheelchair seat cushion is tilted 4 degrees relative to the horizontal plane and the seat back tilted 4 degrees relative to the vertical plane. In the second posture, the wheelchair seat back is reclined 30 degrees backward while the seat cushion is kept in the 4 degree position. The difference between the third posture and the second posture is that the seat cushion is tilted 30 degrees backward also. The occupant sits erect if looked from the side but reclines right-side in the fourth posture.

The wheelchair is tied down on the floor of a vehicle (or a sled) with four belt tiedowns. The occupant is restrained by a shoulder belt and a lap belt. The vehicle or the sled is decelerated from 30 mph with the deceleration pulse shown in Fig. 2.

SIMULATION RESULTS

Table 1 shows the peak values of the responses of the wheelchair-occupant system to the pulse illustrated in Fig. 2. It has been found that, the dummy hip load on the wheelchair cushion increases dramatically when the dummy is sitting in posture 2 and 3 positions. This is mainly due to the large amount of dummy submarining during crashes. This large force could induce injury to the spinal system of the occupant. Comparing with the posture 1, the excursions or forward displacements of the head and chest show a increase for the posture 2 and 3. But because the initial positions of the dummy head in postures 2 and 3 are about 7-8 inches behind the initial position of the head in posture 1 due to the back recline, the maximum forward head positions in these three postures are actually similar. However, in the postures 2 and 3, the initial distances between the shoulder belt and the occupant chest are much greater than that in posture 1. Thus, the shoulder belt forces are higher in postures 2 and 3.

323

Table 1. Comparison of Crash Response for Different Sitting Postures

	Posture 1	Posture 2	Posture 3	Posture 4 (Shoulder belt inside shoulder joint)	Posture 4 (Shoulder belt outside shoulder joint)
Head acceleration (Resultant)(g)	57.3	51.9	65.6	43.3	37.6
Chest acceleration (Resultant)(g)	54.8	64.8	69.6	53.4	42.0
Head forward excursion(in)	12.1	18.0	19.5	14.6	28.6
Chest forward excursion(in)	5.6	7	7.1	5.6	14.2
Hip load on seat cushion(lb)	3470	6870	7491	3227	3714
Shoulder belt force(lb)	2025	2281	2424	1874	2200
Lap belt force(lb)	1687	1965	1602	1560	1604
Wheelchair CG acceleration (g)	35.0	35.1	42.9	49.7	38.6
Rear tiedown force(left)(lb)	4963	4805	5687	5539	5118
Rear tiedown force(right)(lb)	5065	4804	5701	5621	5042
Rear wheel load(left)(lb)	5141	5569	6072	5183	5274
Rear wheel load(right)(lb)	5185	5492	5937	5758	5213

All excursions were obtained at the maximum forward position with respect to the position at the beginning of the impact (t=0)

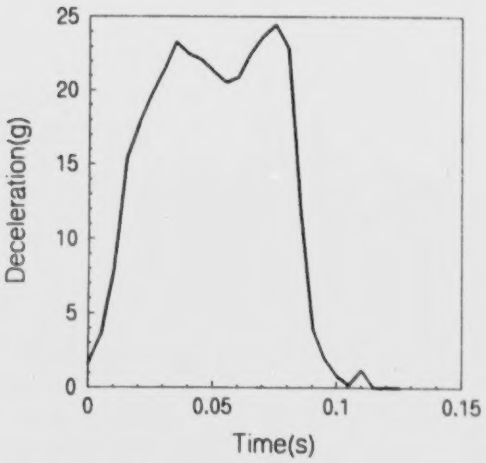


Fig. 2. Sled deceleration pulse

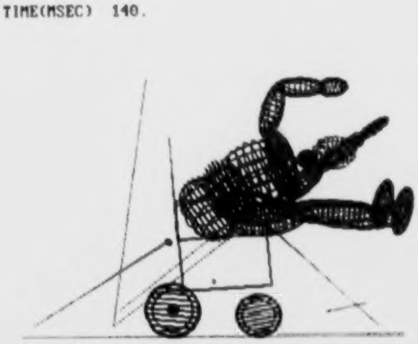


Fig. 3. Shoulder belt slip off the occupant

Weize Kang, Research Scientist
Transportation REC, University of Virginia
1011 Linden Av. Charlottesville, VA 22903, USA
Tel. (804)924-3291, Fax. (804)982-2037
E-mail: wk2j@virginia.edu

BEST COPY AVAILABLE

The results in posture 4 with the shoulder belt falling inside the shoulder joint are similar to the results in posture 1. When the shoulder belt falls outside the shoulder joints, the excursions of the head and chest becomes much larger because the shoulder belt actually slips off the upper torso of the dummy (Fig. 3). This large excursion will increase the chance of injury because the occupant may hit the inside of the vehicle during crashes.

CONCLUSIONS

Computer simulation can be used to predict the crash response of an occupant sitting in a mobility aide while riding in a vehicle. If the sitting posture of an occupant is not in an erect position, a special seat cushion needs to be provided to prevent the large lower torso loads due to the occupant submarining, and the shoulder belt upper anchor point should be adjusted in order to keep the belt in contact with the occupant shoulder. In addition, shoulder belts should fall inside the occupant shoulder joints to avoid the belt slipping off the occupant shoulder during a crash.

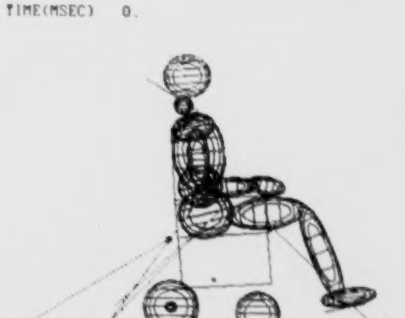
REFERENCES

1. Shaw, G., et. al., "Wheelchair Tiedown Interlaboratory Test", Proceedings of the RESNA'94, June 17-22, 1994, pp. 64-66.

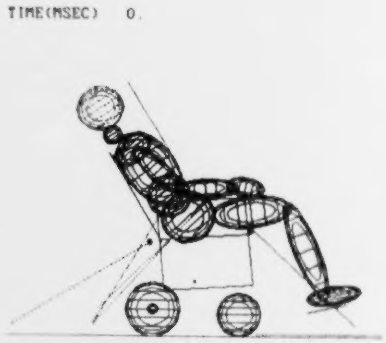
2. Pilkey, W.D., Kang, W., and Shaw, G., "Crash Response of Wheelchair-Occupant Systems in Transport", Proceedings of the RESNA'94, June 17-22, 1994, pp. 61-63.

ACKNOWLEDGMENTS

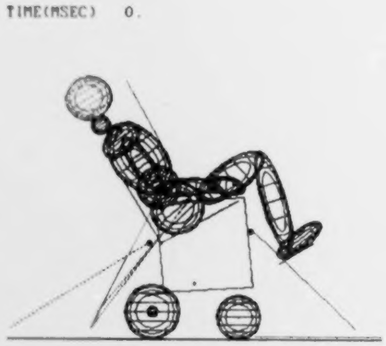
The National Institute on Disability and Rehabilitation Research (NIDRR) sponsored this research.



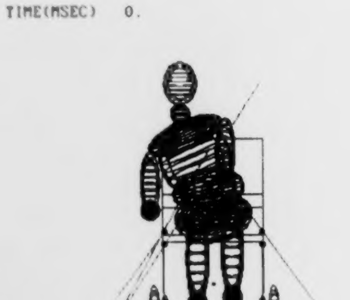
(a) Erect



(b) Back tilt 30 degrees



(c) Back and cushion tilt 30 degrees



(d) Recline to right side

Fig. 1. Different sitting postures

THE AFFECTS OF SHOULDER BELT ANCHOR POSITION ON WHEELCHAIR TRANSPORTATION SAFETY

Gina E.Bertocci, MSME, PE
Rehabilitation Technology and Bioengineering Programs
University of Pittsburgh, Pgh, PA.

ABSTRACT

An investigation of the impact of the shoulder belt's upper anchor point location on crash protection during wheelchair transportation was conducted using a lumped parameter crash victim simulator. While varying the upper anchor point's location in each of three directions, the occupant kinematics and injury criteria of a Hybrid III test dummy were determined. Through comparison of these parameters and their associated trends, it was determined that varying the anchor point's location has a significant impact on the occupant's crash protection.

BACKGROUND

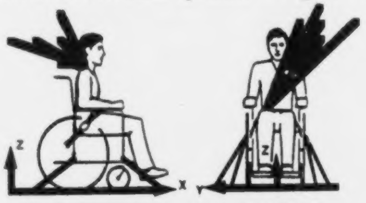
A review of research and development in the area of transportation safety produces a very lengthy and successful history. Perhaps one of the most effective safety measures introduced to this industry is the safety belt, or occupant restraint, which alone is estimated to save 5000 lives each year(1). The design and implementation of this, and other safety devices in the transportation environment are guided by the Federal Motor Vehicle Safety Standards (FMVSS) as mandated by the National Highway Transportation Safety Administration (NHTSA). FMVSS 208, along with several associated Notices of Proposed Rulemaking (NPRM's) to this legislation, specifically addresses occupant crash protection systems(2).

Unfortunately for individuals with disabilities, the parameters set forth in these documents were developed primarily with the intent of application to able-bodied drivers and passengers. Therefore, in this and other areas of transportation safety, those required to travel seated in their wheelchairs have not been able to realize the abundant benefit of the research and development that has taken place in this industry. In fact, direct application of guidelines, such as the prescribed shoulder belt's upper anchor point, to public wheelchair transportation may be impractical in some cases, as physical limitations are imposed by both the wheelchair and the vehicle's interior structure. To investigate the impact these upper anchor point limitations introduce to the wheelchair occupant's crash protection, an analysis employing computer simulations of various anchoring scenarios was conducted.

METHODS

A lumped mass crash victim simulation system, Dynaman, modeling the ISO 10542(3) surrogate wheelchair secured by a four point tiedown system with a 50th percentile male Hybrid III test dummy restrained by shoulder and lap belts, was used to evaluate the affects of varying the position of the occupant restraint's upper anchor point. The simulation model(4), using a deceleration pulse which simulates a 30 MPH frontal impact, has been validated through a series of sled impact tests conducted during the ISO and SAE standards development process.

To systematically determine the affect of varying the location of the upper anchor, a number of simulations were run while varying it's position in only one direction while maintaining the other two coordinate positions. This process was followed for each of the three coordinate directions and is reflected along with the established coordinate systems in Figure 1.



COORDINATE SYSTEMS AND ANCHOR POINT LOCATIONS
FIGURE 1

For each simulation, data regarding the linear acceleration and relative displacement of the head was collected over a 240 msec period. Additionally, traces of head excursions occurring in the horizontal plane were generated and examined as a part of this evaluation. Accelerations profiles of the head were further used to derive the Head Severity Index (HSI) and Head Injury Criterion (HIC).

RESULTS

Variation in the anchor's X-coordinate:

Three simulations which maintained constant Y- and Z-coordinates of the upper anchor point at -24" and -70.5", respectively, were run while varying the X-coordinate through 10.65", -1.35" and -13.35". Table 1, describing peak values of parameters with respect to the anchor's X-coordinate position, generally shows a decrease in their values as the anchor point is moved rearward, or aft.

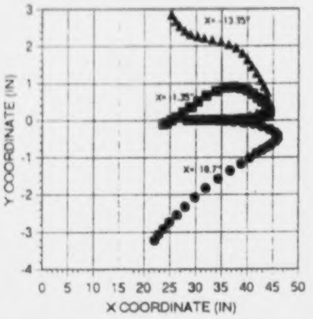
PEAK VALUES UPON VARYING UPPER ANCHOR PT LOCATION IN X-DIRECTION
TABLE 1

UPPER ANCH PT LOCATION(In)			LINEAR HEAD ACCELERATION (Gs)			LINEAR HEAD DISPLACEMENT (In)				INJURY PARAMETERS	
X	Y	Z	Gx	Gz	Gr	X	Y	Z	R	HSI	HIC
10.7	-24	-70.5	-40.8	60.8	67.3	17.9	3.2	4.9	9.3	1793	1548
-1.35	-24	-70.5	-36.7	53.7	59.6	16.2	0.9	5.1	8.1	1074	847
-13.4	-24	-70.5	-36.1	53.5	58.6	15.9	2.8	5.2	7.5	945	765

Injury criterion such as the HIC and HSI have values as high as 1548 and 1793, respectively, for x=10.65", but are seen to decrease to 765 and 945, respectively, with

BEST COPY AVAILABLE

moving the anchor point rearward to x=-13.35". Peak resultant displacement of the head also decreases (from 9.3" to 7.5") with moving the upper anchor point from it's furthest forward to it's furthest aft position. To further analyze this head motion, head excursion in the XY, horizontal, plane was plotted over the entire crash duration of 240 msec, and is shown in Figure 2. This plot shows that despite a slight decrease in the X-directional displacement, there is an increase in the head's Y displacement, as the anchor is moved rearward. It is easy to see from this figure that the head excursion pattern in the XY plane is minimized for the case of x=-1.35 when comparing these simulation runs.



HEAD EXCURSION IN XY PLANE
FIGURE 2

A review of the resultant linear acceleration of the head, as denoted by Gr, also shows a desirable decrease as the anchor point is moved rearward. The peak resultant linear acceleration at the most rearward anchor point is 58.6g's, while in the most forward position is increased to 67.3g's.

Variation in the anchor's Y-coordinate:

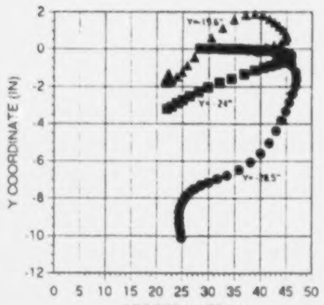
As with the simulations to evaluate the effects of varying the anchor point's X-coordinate, a similar set of simulations was conducted to evaluate the impact of changing the anchor point's Y-coordinate location. In this case, the values of the X- and Z-coordinates were maintained at x=10.65" and z=-70.5" while simulations were run for y=-19.6", -24", and -28.5". These values of Y were arrived at by deviating 5 degrees in either direction from the FMVSS 210 recommended shoulder belt comfort angle of 55 degrees, as measure from the sternum reference horizontal plane to the shoulder belt.

Peak values of measured parameters resulting from these simulations are shown in Table 2, while head excursions are shown in Figure 3.

PEAK VALUES UPON VARYING UPPER ANCHOR PT LOCATION IN Y-DIRECTION
TABLE 2

UPPER ANCH PT LOCATION(in)			LINEAR HEAD ACCELERATION (Gs)			LINEAR HEAD DISPLACEMENT (in)				INJURY PARAMETERS	
X	Y	Z	Gx	Gz	Gr	X	Y	Z	R	HSI	HIC
10.7	-19.6	-70.5	-30.7	59.8	67.3	17	2.7	4.9	8.8	1777	1491
10.7	-24	-70.5	-40.8	60.8	67.3	17.9	3.2	4.9	9.3	1793	1548
10.7	-28.5	-70.5	-40.1	61.7	67.2	19.1	11.8	5.3	9.8	1733	1446

Although the resultant head acceleration varies insignificantly with moving the anchor point outboard,



HEAD EXCURSION IN XY PLANE
FIGURE 3

e resultant head displacement does increase from 8.8" to 9.8". Additionally, Figure 3 shows that moving the anchor point away from the medial plane results in a noticeable increase in the head's excursion to the occupant's right side. Injury criteria for this set of simulations show negligible variation with changing the anchor position.

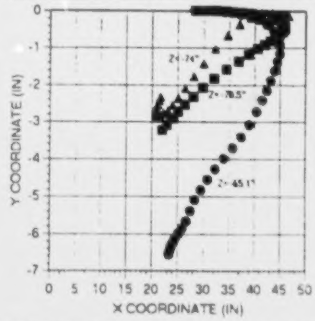
Variation in the anchor's Z-coordinate:

Simulations to evaluate the effect of moving the upper anchor point either upward or downward from the baseline case were conducted with x=10.65" and y=-24". Z-coordinate points were derived by varying 5 degrees in either direction from the FMVSS 210 recommended shoulder belt comfort angle of 55 degrees.

Table 3 records the peak values of select parameters, while Figure 4 shows the head's excursion while varying the upper anchor point's Z-coordinate.

PEAK VALUES UPON VARYING UPPER ANCHOR PT LOCATION IN Z-DIRECTION
TABLE 3

UPPER ANCH PT LOCATION(in)			LINEAR HEAD ACCELERATION (Gs)			LINEAR HEAD DISPLACEMENT (in)				INJURY PARAMETERS	
X	Y	Z	Gx	Gz	Gr	X	Y	Z	R	HSI	HIC
10.7	-24	-65.1	-37.7	55.4	61	17	6.4	5.3	8.4	1108	849
10.7	-24	-70.5	-40.8	60.8	67.3	17.9	3.2	4.9	9.3	1793	1548
10.7	-24	-74	-43	63.7	70.1	18.5	2.8	4.7	9.5	2045	1712



HEAD EXCURSION IN XY PLANE
FIGURE 4

Increase in the head's resultant acceleration, from 61 to 70.1g's, occurs with moving the anchor point upward to z=-74". Correspondingly, injury criteria increase substantially with this upward movement such that values of HIC and HSI are at their highest for all simulations.

BEST COPY AVAILABLE

BELT ANCHOR POSITION AFFECTS

Upon reviewing the head displacement pattern in the horizontal, or transverse plane, it is seen that having the shoulder belt's anchor point in the highest position (i.e. z=-74" and a belt angle of 60^0) provides the greatest restriction to head excursion in the Y direction. When the anchor point is lowered to z=-64" (belt angle = 50^0), the shoulder belt no longer passes over the clavicle and instead crosses the occupant below the acromion which allows the shoulder to rotate free from the belt resulting in increased head excursion in the transverse plane. Head excursion in the Y direction, associated with the low anchor point (z=-64"), is 6.4", whereas the highest anchor point (z=-74") produces a head excursion of 2.8".

DISCUSSION

As indicated by the results obtained, moving the shoulder belt's upper anchor point rearward producing a shallow belt angle beyond the shoulder in the XZ plane, improves the wheelchair occupant's crash protection. Decreases occurring in the head's linear acceleration when the anchor point is moved rearward are significant and could represent a difference in the severity of an injury in such a crash as evidenced by the changes in injury criteria. The most rearward positioning locates the shoulder belt such that contact with the shoulder is increased which serves to better couple the occupant with the vehicle. A closer coupling of the occupant and vehicle through the restraint system will allow the belt's pretensioner (if present) to be activated prior to significant excursion, much the way a belt with little or no slack will respond. Ultimately this will increase the occupant's potential for "riding down the crash" at the same rate as the vehicle structure, thereby reducing the occupant's crash pulse. In affect, moving the shoulder belt's anchor point rearward serves to approach the anchoring configuration of an integrated seat which anchors the shoulder belt just above the occupant's shoulder, providing improved crash protection.

Review of results which move the upper anchor point inboard or outboard indicate that a more inboard positioning of this point, causing the belt to cross the thorax closer to the neck, significantly reduces the head's excursion in the Y-direction. With moving the anchor point outboard, the shoulder belt no longer passes over the clavicle, but instead crosses the upper thorax at a point below the shoulder. This positioning permits the shoulder to rotate freely, resulting in increased head and upper torso excursions.

Varying the shoulder belt angle through 50, 55 and 60 degrees by adjusting the height (Z-coordinate) of the anchor point shows that a higher anchor point location where the shoulder belt crosses the thorax closer to the neck, produces an increase in head accelerations and injury criteria. A HIC value of 1712 is the highest value produced for all simulations and is thought to be unacceptable based upon the FMVSS limit of 1000 for HIC. However, a lower anchor point (z=-65.1") allows for increased head excursion in the Y direction since the shoulder belt no longer crosses the thorax at the center of the clavicle instead passing lateral to the clavicle's midpoint which allows for shoulder rotation.

When comparing the results of all conducted simulations, it is seen that for a Hybrid III dummy undergoing a 30 mph frontal crash, an upper anchor point with coordinates x=-13.35", y=-24" and z=-70.5" provides the best crash protection. This anchor point produces a shoulder belt angle of 55^0 with a horizontal plane taken through the sternum reference, and is located approximately 13" behind the occupant's shoulder resulting in a belt angle of 27^0 in the XZ plane. With the upper anchor point in this location, the resulting HIC value of 765, and the head acceleration in the Z direction of 53.5g's, are within existing FMVSS HIC requirements of 1000, and proposed safety standards of Gz less than 70g's. Conversely, many of the other modeled anchor points do not meet these requirements.

Although it is of interest to simulate the affects of various anchor points, outside of the laboratory transporters are usually limited in the availability of structurally suitable anchor points. Windows, seat positioning, and the vehicle's structural integrity often reduce anchor point options in fixed route or paratransit vehicles. Since in public transportation the shoulder belt's anchor point is generally permanently fixed, it is of paramount importance that further investigation and sled impact testing be conducted, as the point of anchorage can have a large impact on the wheelchair occupant's crash protection.

REFERENCES

1. Digges,K. Rehab Engr Course Notes, Oct, 1994.
2. NHTSA. 49CFR571.208, Occupant Crash Protection, 1991. US Department of Transportation, Wash., DC.
3. International Standards Organization. ISO Draft Standard, Wheelchair Tiedown and Occupant Restraint Systems for Motor Vehicles, Oct, 1994.
4. University of Virginia/University of Pittsburgh. Paper for ISO Working Group 6 of TC 173/SC1, Wheelchair Tiedown and Occupant Restraint Systems, Nov, 1993.

ACKNOWLEDGEMENTS

Research conducted as a part of this study was supported by NIDRR Project #H133E30005, RERC on Technology to Improve Wheelchair Mobility.

Gina E. Bertocci,MSME,PE - Rehab Tech Prog
University of Pittsburgh - UPARC
Pittsburgh, PA. 15238
(412)-826-3138 GINABER@PITT.EDU

BEST COPY AVAILABLE

POTENTIAL HAZARDS OF WHEELCHAIR LAP BELTS

Peter W. Axelson & Denise A. Chesney
Beneficial Designs, Inc.

ABSTRACT

Wheelchair lap belts are commonly used to maintain the appropriate pelvic position of a wheelchair user. Through our research and consulting experience we have found that accidents and incidents have occurred as a result of misapplication, and/or misuse of wheelchair lap belts. There appears to be a lack of awareness of the hazardous situations that could potentially occur when a wheelchair lap belt is not selected, mounted and used properly. A lap belt mounted to the wheelchair at the wrong location will create an inappropriate lap belt angle. Excessive vertical movement of the lap belt and clearance underneath the lap belt would then facilitate sliding in the seating system. With careful selection and use, a wheelchair lap belt may serve as an effective device for pelvic positioning without putting the user at risk of strangulation, suffocation or other injurious situations.

BACKGROUND

It is widely known that when seating an individual, a stable base of support is essential. A wheelchair lap belt is one of the simplest and most common devices used to achieve pelvic stabilization. Since the success of the entire seating system often relies upon proper pelvic positioning, careful attention must be paid to the selection and use of the lap belt (1). The rehabilitation industry has essentially accepted a lap belt angle of 45 to 90 degrees to the seating surface as a standard; although written standards do not exist.

OBJECTIVE

The objective of our work was to analyze two seating systems involved in wheelchair incidents to determine the appropriateness and the level of safety provided by all positioning devices, particularly wheelchair lap belts. The selection, method and location of attachment, and the effectiveness of all positioning devices used on the seating systems were examined. Existing knowledge and industry standards were also taken into consideration during the analysis.

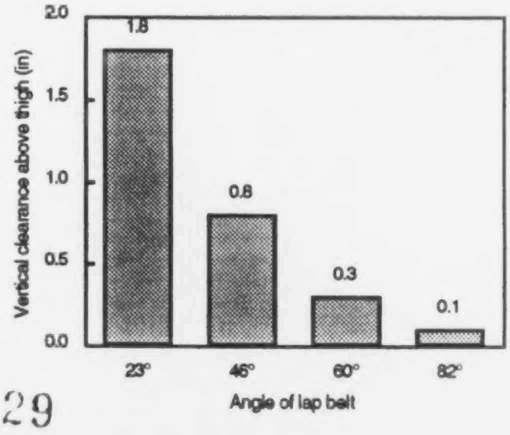
METHOD/APPROACH

Evaluation of the two different seating systems (Cases A and B) began with detailed documentation and measurements of the seating components. ANSI/RESNA wheelchair standards measurement methods (2) were used. The wheelchair lap belts were evaluated to determine if they met the following criteria for safety and function:

1. When properly positioned, the wheelchair lap belt: stabilized the pelvis; maintained proper pelvic positioning, and allowed pelvic movement, if appropriate.
2. The angle of the lap belt was at a minimum of 45 degrees from the seating surface (with 90 degrees being a vertical lap belt).
3. The point of attachment of the lap belt was as close to the seating surface plane as possible.
4. The length of the lap belt was adjustable and, once adjusted, the belt remained fixed in length.
5. The lap belt was not used as a seat belt in a motor vehicle.
6. Lower extremities were properly positioned.

To objectively evaluate specific configurations of the lap belt in Case B (described on next page), computer drawings were created using AutoCAD. Measurements of a small subject group were made to determine the approximate maximum percentage of compression of the thigh and of the torso that could be applied without pain or injury. Different lap belt attachment points and angles were simulated on the computer. Measurements were made to determine the effects of these various seating configurations on the amount of vertical clearance that could occur under the lap belt, assuming that the torso would be compressed 28% against the lap belt in a sliding situation.

Effects of the Lap Belt Attachment Point and Angle on the Amount of Vertical Clearance Above the Thigh



The results of the computer simulations of different lap belt configurations are shown in the bar graph. As the lap belt attachment point was moved forward along the seat rail, the angle between the lap belt and seating surface increased and the amount of vertical clearance that could occur under the belt decreased.

If the lap belt is attached such that the angle is greater than 60 degrees, when the lap belt pivots there is only a small increase in the amount of clearance under the lap belt. For example, in Case B assuming that the torso can compress 28%, a lap belt mounted at 45 degrees can pivot to create a vertical clearance that is over 250% more than the vertical clearance for a lap belt mounted at 60 degrees.

In addition, a literature search was conducted to identify the current knowledge within the seating industry. Electronic databases were searched for incidents and accidents involving lap belts and other positioning devices.

RESULTS

In addition to the two seating systems that instigated the investigations (A,B), four other incidents involving significant injury to the wheelchair user were identified: one by a colleague (C), and three through DEN Reports (Device Electronic Network) (D,E,F).

CASE	DESCRIPTION OF INCIDENT
A	A child with spastic diplegic cerebral palsy was riding on a bus on his way to school when he slipped down in his wheelchair and was asphyxiated by his H-harness.
B	A child with athetoid cerebral palsy slid down in her wheelchair and was asphyxiated by her butterfly chest support.
C	An elderly woman slid down in her wheelchair and was asphyxiated by her torso restraint.
D	Patient was found sitting on footrest of wheelchair with seatbelt around her neck.
E	Patient was found dead, half out of wheelchair with the belt up around throat.
F	Patient was left unattended in wheelchair with the wheelchair belt on. The patient was found to have slipped down in the wheelchair with arms extended above the head and belt around patient's chest.

Analysis of the two seating systems involved in Cases A and B revealed the following:

Case A:

The seating system contained an H-harness, but not a lap belt.

Case B:

The seating system contained a lap belt and a butterfly chest support.

When fastened, the angle between the lap belt and the seating surface was less than 45 degrees.

The lap belt was attached to the seat rail behind the seat-back junction.

The lap belt did not contain a mechanism for maintaining the proper length and thus could be easily lengthened/loosened.

The foot/ankle restraint straps were too long and the Velcro closure was not secure, thus the position of the lower extremities was not properly maintained.

DISCUSSION

The results of these wheelchair incident investigations indicate that careful attention to the following issues must be made in order to ensure a safe seating system.

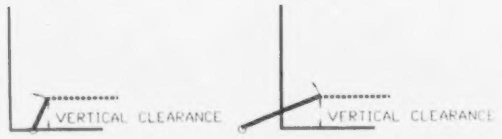
Use of Chest Supports

When using an anterior chest support, proper positioning of the pelvis must be maintained at all times. Although this seems like common sense, it is sometimes overlooked or neglected.

Angle of Lap Belt

The angle of the wheelchair lap belt should ideally be between 60 and 90 degrees from the seating surface. This angle creates a downward pull across the thigh/abdominal intersection. As the lap belt pivots about its attachment point, its rotation results in less vertical movement than for a lap belt mounted at a lesser angle. The resistance provided by the lap belt prevents the pelvis from sliding under the lap belt and thus makes it very difficult for a user's pelvis to slide forward.

Effects of Different Lap Belt Angles Attachment Points



Ideal
60 to 90 degrees

Incorrect
less than 45 degrees

Point of Attachment of Lap Belt

A lap belt attached behind the seat to back junction (for instance on the seat rail behind the user) will almost always result in a lap belt angle less than 45

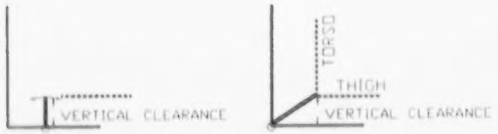
BEST COPY AVAILABLE

degrees. When the lap belt pivots upward, there is an increase in the amount of clearance under the lap belt. The probability of sliding under the restraint is thereby increased.

If the lap belt is attached such that the angle is 90 degrees when the lap belt pivots, the amount of verticle clearance under the lap belt can only decrease. When looking at a 90 degree lap belt, it is not obvious how a vertically oriented lap belt would prevent sliding. However, since the vertical clearance in the belt cannot increase, the user cannot slide underneath the belt and thus can not slide forward.

If the lap belt is mounted at the seat to back junction, the angle will almost always be less than 45 degrees because the torso is almost always thicker than the legs.

Effects of Different Lap Belt Attachment Points



90 degree lap belt mount

Mouting at seat to back junction is less than 45 degrees

Other Lap Belt Issues

It is critical that the length of the lap belt is maintained during use. Once cinched to the proper tightness, it should not be possible for the user to loosen the lap belt through casual contact or during normal daily activities.

When in a seated position, flexing at the hips by raising one's legs facilitates posterior tilting of the pelvis. Therefore, if the user tends to move his/her legs or feet and the lower extremities are not properly restrained, the user might slide under the lap belt.

Wheelchair lap belts are designed to be used as postural supports, not as pelvic restraints in a motor vehicle. They are not designed to withstand high static or impact loads. Use of a wheelchair lap belt as motor vehicle seat belt may lead to serious injury or death in the event of a collision, evasive maneuver, or even under normal driving conditions. When traveling in a motor vehicle, a proper seat belt and shoulder harness attached to the vehicle and meeting SAE safety standards must be used.

CONCLUSION

A wheelchair lap belt should be attached forward of the seat-back junction and as close in height as possible to the seating surface. When the lap belt is attached in this location, it usually creates the desired 45 to 90 degree angle. By minimizing the length of the lap belt, the amount of clearance that can occur under the lap belt is also decreased.

Should there be seating standards to ensure that wheelchair users are provided with safe seating systems?

Standards exist for automobile and aircraft seating. The expertise in the wheeled mobility and seating industry has progressed. The expertise is now available to develop seating standards that address basic seating needs. Therefore, we feel that the time has come for the development of wheelchair seating standards that address basic seating needs. Improper seating systems have caused several fatalities. Many users are currently at risk. If standards for wheelchair seating were implemented, incidents and accidents could be prevented and would provide wheelchair users with safer seating systems.

REFERENCES

(1) Bergen A.F., "A Seat Belt Is a Seat Belt Is a ...". *Assistive Technology* 1989; 1(1):7-9.

(2) ANSI/RESNA WC/07 Wheelchairs – Determination of Seating and Wheel Dimensions, 1991.

ACKNOWLEDGMENTS

Our thoughts are with the families and friends involved in the cases mentioned in this article.

EVALUATION OF A PROGRAM TO TEACH SEATING CLINICS HOW TO BUILD CUSTOM CAR SEATS

Steve Ryan, Wes From, Kevin Day
The Hugh MacMillan Rehabilitation Centre
Toronto, Ontario, CANADA

Abstract

Recently, we developed a restraint system to convert a wheelchair seating system into a custom car seat for children with positioning problems. The ability and willingness of seating clinics to modify their construction techniques to comply with federal regulatory requirements were critical to the performance of the product.

To evaluate this, we recruited ten North American seating clinics and asked them to each construct a custom car seat using the restraint system and hardware we developed. We gave them workshop instructions and each completed a questionnaire. They returned their completed car seats and questionnaires for our review.

The results suggest that, with minor revisions to the workshop manual and hardware templates, seating clinics could create effective custom restraint systems for their young clients.

Background

Being properly restrained in a motor vehicle presents special problems for many children who require specialized postural seating support. Standard commercial car seats and even specialized commercial car seats for children with disabilities often do not provide the degree of postural support needed.

Parents often have no choice but to use the seating system from their child's wheelchair in the car with the child secured by the vehicle lap belt and the seating system's postural straps. While this may provide adequate postural support, it could contribute to serious occupant injury or death during an automobile accident.

In 1989, Transport Canada issued Canada Motor Vehicle Safety Standard (CMVSS) 213.3 to regulate the performance of systems used to secure people with disabilities. This standard stipulates the requirements for both *production* car seats (e.g. Snug Seat, Carrie Car Seat, Columbia, etc.) and *custom* car seats. The regulation requires that all production restraint systems be tested dynamically to evaluate their crashworthiness. Custom restraint systems are exempt from this particular requirement but are deemed compliant if they meet all other aspects of the standard (1).

This standard allows seating clinics to create customized seating systems that provide a new level of vehicle occupant safety for their young clients.

In practice, adopting this regulation is difficult for clinics and can result in the creation of a system that is both cumbersome and costly. To address this issue, a unique carrier restraint called the *FRAME-IT* system was developed and tested for children between 9 and 18 kilograms (20-40 lbs). The advantage of this system is that a custom seating insert from a wheelchair can be readily inserted into it to provide individualized occupant protection (2,3).

While *FRAME-IT* alone meets about 90% of the requirements of CMVSS 213.3, seating clinics must be willing to, and capable of, making their wheelchair seating systems meet the remaining sections of the regulation, and attaching the interface hardware for the restraint system. Local seating clinics suggested that they needed help understanding how to do this. Therefore, a workshop manual was written for seating clinics.

The manual instructed clinics how to modify their methods and materials to comply with the regulations. The manual explained which types of foams and upholsteries are acceptable, how the restraint interfacing hardware should be attached, and what seating components are permitted when the child uses the device as a car seat.

To understand the effectiveness of the manual and the ability of seating clinics to construct an appropriate seating system, an evaluation program was devised.

Objective

The objectives of the evaluation program were to:

- ▸ understand how clinics currently construct wheelchair seating systems
- ▸ understand to what extent seating clinics would and could modify their construction techniques to meet

332

federal regulations
- identify problems clinics had in fitting a custom seat to the *FRAME-IT* system
- identify problems interpreting the manual
- identify ways to improve the manual

Method

Four clinics from various regions in Ontario, two clinics from Western Canada, one clinic from a Maritime province, and one clinic in each of the South Western, mid-Western and Eastern regions of the United States were recruited to represent a variety of regional perspectives. Each clinic received a *FRAME-IT* system with interfacing hardware, a workshop manual, a Consumer Information Sheet (now called a Certificate of Compliance), a user's guide and an instructional videotape for parents.

Each clinic built a custom seating system to fit a hypothetical client having a specific diagnosis and body dimensions. Each participating clinic was also asked to answer a questions about the manual, the problems they had adapting their fabrication techniques, and their confidence in constructing a custom restraint system.

Results

Each of the ten clinics returned a custom car seat using the *FRAME-IT* system provided. The evaluation then took two directions: one was a compilation of the information returned by the clinics, the other was a detailed analysis of the seating systems they manufactured to identify how well they complied with the instructions and CMVSS 213.3.

System Analysis

All of the interface hardware that the clinics installed was safely mounted, although half of the clinics did not use a thread locking compound on the screws. Difficulties were experienced when attaching three seating systems. In one case, the seat could not be connected to the frame.

A few of the custom seating systems were slightly smaller than the recommended size and two had recline angles greater than what the manual recommended. While these deviations did not contravene CMVSS 213.3, they may have reduced the effectiveness of the system slightly.

Five clinics did not provide the required Certificate of Compliance with the system they sent. Three of the provided Certificates were incomplete, missing information such as the client's name and the clinic's name.

In spite of the list of generic compliant and non-compliant materials in the workshop manual, each seating clinic was responsible for investigating their own materials compliance with flammability and compression deflection requirements. Some of the foams in the seating systems could not be identified, and as such, compliance could not be established.

Clinics' Evaluation

Generally, respondents felt the written instructions were detailed and the illustrations were helpful. Most thought using the manual would be easier the second time through. Suggested improvements included: providing colour coded sections to make it easier to find specific items, justifying specific construction requirements, specifying brands and suppliers of compliant materials listed in the manual's appendices.

Clinics were unanimous in their view that sections of the regulation are very difficult or impossible to interpret without the workshop manual. All rated the manual to be clearer than the federal regulations.

Other comments and corrections that were suggested for the manual included:
- more and better illustrations
- clarification and justification of specific requirements
- specific trouble-shooting guidelines.

Clinics reported that they were concerned about their seating materials' compliance with the flammability requirements. One clinic suggested that there may be some materials that a client needs for clinical reasons but do not comply, while another noted that it was difficult getting accurate information on compliance from their suppliers.

Clinics identified areas of concern with the *FRAME-IT* system itself:
- mounting the interface hardware was awkward
- there were problems with space constraints
- alignment problems were noted
- need to better accommodate growth
- improve manufacturing finish
- improve the ease of operation

Discussion

The primary concern with providing undersized seating systems is that the interfacing hardware may be difficult to attach properly or may be exposed to a greater risk of inadvertent damage. Increasing the hip angle beyond the recommended 90-100 degrees increases the possibility that the occupant will sustain abdominal injuries by "submarining" when the belts slide above the bone of the pelvis.

It is necessary that the clinics validate the compliance of the materials they use for themselves, either directly from the manufacturer or through testing, even if the products are listed in the workshop manual. Small formulation changes to materials could be enough to reduce the combustion resistance to the point where it no longer passes the regulation.

CMVSS 213.3 and the workshop manual require that the consumer be assured in writing that the seat has been constructed according to the standard, and as such *must* be included. This document also reminds the consumer of the importance of proper securement and encourages them to follow the written instructions found in the user's manual.

Although most respondents did not report there to be a problem with the clarity of the manual, several suggestions are being incorporated to make it easier to read and use. Templates and new procedures are now provided to ease the task of attaching the interface hardware. Also, some changes have been made to the hardware package that comes with the *FRAME-IT* system to make it faster and easier to install.

One clinic raised concerns about their liability in creating custom car seats for their clients. In Canada, clinics are required to follow CMVSS 213.3 if parents are using the wheelchair seating system as a car seat. The workshop manual for *FRAME-IT* was written to interpret the requirements of this standard. As such, clinics following the manual are meeting the regulatory requirements. It cannot be claimed that the child will travel risk-free in the family car, however, the likelihood of serious injury to the child will be reduced if clinics observe the workshop procedures and parents heed the consumer instructions.

In the United States, FMVSS 213 regulates the performance of *production* car seats for children weighing 40 pounds and under. There are *no* provisions contained in the regulation for custom car seats nor are there requirements for child restraint systems for children weighing over 40 pounds. Although CMVSS regulations are binding in Canada only, it is recommended that American clinics follow the procedures detailed in the manual. In so doing, the authors believe that clinics will meet the intent of FMVSS regulations.

The ability of participating clinics to comply with the relevant requirements of the manual (and hence CMVSS 213.3) is encouraging. We believe that the *FRAME-IT* system is an important first step toward providing safe transportation for many young children with disabilities. However, it is essential that better, easier-to-use custom restraint systems will developed to minimize the likelihood of misuse and maximize the level of occupant protection provided.

References

(1) Ryan S.E., Young M., Fong D., and Naumann S. *Dynamic Testing of Custom Seating Inserts for Transporting Children with Physical Disabilities in Motor Vehicles*, Proceedings of RESNA International 1992: 89-91.

(2) Ryan S.E., Fong D., Young M., Sotiropoulos J., and Naumann S., *Development of a System for Using Custom Seating Inserts in Motor Vehicles*, Syllabus of the Eighth International Seating Symposium, 1992, Vancouver, BC: 107-110.

(3) Ryan S.E., Mochan L., Ataides A., Milner M. *Understanding Flammability Standards: Guidelines for Classifying Materials Used to Construct Custom Seating Systems*, Proceedings of the Canadian Seating and Mobility Conference, 1993.

Acknowledgements

We would like to thank the ten paediatric clinics who participated in this evaluation program. We wish to acknowledge the support of the National Health Research and Development Programme (Health and Welfare Canada), the Ontario Ministry of Health (through the Ontario Rehabilitation Technology Consortium), the Rotary Club of Leaside (Toronto) and SOS Rehabilitation Technologies (Montreal, Quebec).

Steve Ryan
Rehabilitation Engineering Department,
The Hugh MacMillan Rehabilitation Centre,
350 Rumsey Road,
Toronto, Ont. CANADA M4G 1R8
Tel: (416)424-3855 ext. 526, Fax:(416)425-1634
E-mail: *ortcsr@oise.on.ca*

DEVELOPMENT OF A COGNITIVE ASSESSMENT BATTERY FOR EVALUATING READINESS FOR POWERED MOBILITY

Donita Tefft,MA,CCC-SP, Jan Furumasu, BS,PT, Paula Guerette, PhD
RERC on Technology for Children with Orthopedic Disabilities
Rancho Los Amigos Medical Center, Downey, California

ABSTRACT

A child's ability to operate a powered wheelchair is influenced by a number of factors including physical access, cognitive developmental 'readiness', motivational and learning styles, and sensorimotor integration. While physical access is no longer the primary hinderance to wheelchair operation, limited information is available to therapists about other factors to assist them in determining a young child's readiness for powered mobility. The current project originated from clinicians' desire to better quantify the skills necessary to functionally operate a powered wheelchair, and to improve the trial-and-error approach commonly used to determine readiness for powered mobility. To achieve this objective, an assessment tool is being developed to evaluate the cognitive skills that influence functional powered mobility in young children (18 to 36 months), and to document the relationship between cognitive skills and performance on an age-appropriate powered mobility program. The present paper describes the development and preliminary validation of the battery.

ASSESSMENT BATTERY DEVELOPMENT

Past research into readiness for powered mobility influenced the basis of the current study. Verburg (1) questioned the use of tests standardized on able-bodied children as measurement tools for children with disabilities. In addition, he suggested utilizing a Piagetian-based approach for evaluating developmental readiness. Piaget's theory of sequential stage development within distinctly different skill domains is a well researched and validated theory of infant/toddler cognitive development (2). The Piagetian-based approach has been found to be appropriate for children with a diverse range of disabilities (e.g., mild to profound developmental delays, cerebral palsy, limb deficiencies, and visual or hearing impairments) (3). A Piagetian-based framework allows the clinician to determine a child's developmental strengths and weakness in a number of skill domains, whereas traditional, norm referenced tools often indicate only a global developmental age (i.e., scores reflect an average of all skill areas). These summary scores can be misleading as children with the same global developmental age can have very different developmental skills, which result in widely varied learning abilities. Since the assessment battery under development was to be used with children with disabilities and since scores on specific domains were desired to predict wheelchair performance, a Piagetian-based approach was chosen.

It was determined that no single existing assessment tool met all the study requirements (i.e., Piagetian-based scores, appropriate for ages 18-36 months; does not penalize children with motoric limitations), consequently, an assessment battery was developed for use in this study. Five Piagetian-based developmental skill domains were selected for inclusion in the assessment battery based upon input from ten experts in the fields of early child development, occupational therapy, speech/language pathology, and powered mobility. These domains were cause/effect, object permanence, problem-solving, spatial relations, and symbolic play. Piaget identified different phases and stages of development for children within these domains. At each stage of development, a child demonstrates specific behavioral attributes across skill domains. Children progress through each skill domain in a hierarchical manner, but may achieve different stages of development across the skill domains (e.g., stage V in problem solving and stage VI in cause-effect).

The assessment battery incorporated tasks along the five cognitive domains from several standardized developmental batteries (2,4,5,6,7). Since the battery was to be administered to children with functional limitations, it was essential that the response requirements not penalize children with motoric disabilities. Therefore, the assessment battery materials were individually modified to allow children with various physical limitations to lift, move, or manipulate the objects; care was taken to insure that the basic task premise always remained the same. For example, in object permanence tasks, small pieces of construction paper were substituted for large cloth napkins for children with limited strength, grasp, and/or range of motion. This battery was then pilot tested with three children. Further revisions were made with the final battery consisting of eighty-three tasks.

METHOD

At this time, twenty-two children between the ages of 18 and 36 months have completed the assessment battery. Only children with diagnoses not typically associated with central nervous system involvement were included (e.g., muscle disease, spinal cord injury, arthrogryposis). This served to minimize the influence of sensorimotor integration problems upon powered mobility. Results of previous functional evaluations performed with each child were reviewed prior to cognitive assessment to determine if modified materials should be used. The assessment was conducted in a location comfortable to the child and relatively free of distractions. Dependent upon the child's attention span, the test was administered 'over one to three sessions, which were completed within a two week period. All sessions were videotaped and later reviewed and scored by the three staff on this project. The actual score on each item was based on the nature of the child's response. If the child performed the task the required number of times, she received a 'correct' score for this task. An 'emerging' score was received, based upon the qualitative nature of the child's responses or if she performed a task fewer than the required number of times. If a child was unable to perform a task at all, she received an 'incorrect' score for this task.

When twenty-five children have completed the study, Rasch analysis will be applied to the developmental data in the five developmental domains in order to establish the hierarchical nature of the items within each developmental domain, and to eliminate misfit items. Rasch analysis is useful in developing measurement scales that have a hierarchic, unidimensional structure (8). Rasch analysis provides a means for clustering data such that certain 'misfit' items can be identified and excluded from a scale. Theoretically, the items that remain all measure something along a single, unidimensional content domain.

Data from four children have been scored independently by two raters to establish an index of interrater agreement on the cognitive assessment battery. Before completion of the project, six more children will be scored independently. In addition, the responses made by 9 children were rescored 8 to 12 months later to determine intraobserver 'drift' in ratings.

RESULTS

Interrater Agreement. The Kappa statistic was used to determine the proportion of agreement (or interchangeability of raters' scores) between raters (9). Kappa scores ranged from .73 to .93 across the five scales (See Table 1). Scores for object permanence, problem solving, spatial relations, and symbolic play were significantly above chance. Landis and Koch (10) suggest that Kappa scores of .75 and above represent excellent interrater agreement above chance, and scores between .40 and .75 represent fair to good agreement above chance.

TABLE 1. Interrater agreement across developmental domains

Cognitive Domain	Kappa	Z-Score
Cause/effect	0.73	NS
Object permanence	0.92	1.79*
Problem Solving	0.93	2.00*
Spatial relations	0.89	1.93*
Symbolic Play	0.84	1.80*

*P< .05

Drift. The Kappa statistic was also used to determine consistency in intraobserver ratings over time. Kappa scores for drift ranged from .54 to .86 (See Table 2). The consistency of ratings for all five cognitive domains were significantly above chance (10). While the Kappa score for cause/effect appeared to be lower than the others, there was nevertheless a 97% consistency in these ratings across time (122 of 126 ratings identical).

TABLE 2. Intraobserver agreement across time

Cognitive Domain	Kappa	Z-Score
Cause/effect	0.54	2.41**
Object permanence	0.75	2.66**
Problem Solving	0.86	3.14**
Spatial relations	0.86	2.68**
Symbolic Play	0.73	2.56**

**P< .01

DISCUSSION

A Piagetian-based developmental assessment approach delineates a child's cognitive development abilities within various cognitive skill domains. Since it is not unusual for a child to demonstrate different developmental ages across various cognitive domains (2), it is important to evaluate these cognitive domains separately. Certain cognitive abilities may be more influential than others in a child's readiness to learn new tasks, such as functional operation of a powered mobility device. This project is developed an Piagetian-based cognitive assessment battery which evaluates a child's various stages of cognitive development. Preliminary interrater agreement and intraobserver 'drift' appear significantly above chance for this assessment tool. When twenty-five children have completed the project, further analysis of the assessment battery will be conducted using the Rasch model. At this point, the total number of items in the evaluation will be reduced by eliminating 'misfit' items. In addition, the analysis will convert ordinal data to interval data and cluster tasks together in similar groups. Following this process, scores on these developmental clusters will be used in a regression analysis to predict scores in the powered mobility program.

When the project is complete, it is anticipated that a revised cognitive developmental assessment battery and an age-appropriate powered mobility program will be available to assist clinicians in the decision-making process when prescribing a powered wheelchair. Once important cognitive skills are identified, it will be possible for these areas to be addressed early in a child's intervention program. Future research can also be initiated to investigates additional influential factors in functional powered mobility such as sensorimotor integration, motivation, and learning styles.

ACKNOWLEDGEMENTS

Funding for research was provided by the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant No. H133E00015. Opinions expressed in this paper are those of the authors and should not be construed to represent opinions or policies of NIDRR.

REFERENCES

1. Verburg, G. (1987). Predictors of Successful Powered Mobility Control. In Jaffee (Ed.) *Childhood Powered Mobility: Developmental, Technical and Clinical Perspectives. Proceedings of the RESNA 1st NW Reg Conf, Seattle, WA.* Washington, DC: RESNA, (pp. 70-104).

2. Uzgiris, I. (1976). Organization of sensorimotor intelligence. In M. Lewis (Ed.), *Origins of Intelligence: Infancy and Early Childhood.* New York: Plenum Press, (pp. 135-189).

3. Dunst, C. (1980). *A Clinical and Educational Manual for Use with the Uzgiris and Hunt Scales of Infant Psychological Development.* Austin, TX: Pro-Ed.

4. Uzgiris, I., Hunt, J. (1975). *Assessment in Infancy: Ordinal Scales of Psychological Development.* Urbana: University of Illinois Press.

5. Bayley, N. (1969). *Bayley Scales of Infant Development.* New York: Psych Corporation.

6. Knobloch, H., Stevens, F., Malone, A. (1980). *Manual of Developmental Diagnosis.* Hagerstown, MA: Harper and Row.

7. Westby, C. (1988). Children's play: Reflections of social competence. *Seminars in Speech and Language, 9,* 1-14.

8. Wright, B.D., Masters, G.N. (1982). *Rating Scales Analysis.* Chicago: Mesa Press.

9. Fleiss, J.L. (1981). *Statistical Methods for Rates and Proportions, 2nd Edition.* New York: John Wiley and Sons.

10. Landis, J.R. and Koch, G.G. (1977). The Measurement of Observer Agreement for Categorical Data. *Biometrics, 33,* 159-174.

Donita R. Tefft
HB222
Rancho Los Amigos Medical Center
7601 E. Imperial Highway
Downey, CA 90242
(310) 940-8294
(310) 803-8892 (Fax)

AN INTEGRATED PILOT SYSTEM TO INCREASE THE AUTONOMY OF DISABLED AND ELDERLY PEOPLE IN MOBILITY AND MANIPULATION .

Vincenzo Genovese, Anselmo Mantuano, Giovanni Ratti, Angelo M. Sabatini, Paolo Dario
Advanced Robotics Technology and Systems (ARTS Lab)
Scuola Superiore Sant' Anna, Pisa, Italy

ABSTRACT

In this paper we describe an integrated system dedicated to motor handicapped people. The system is composed by input devices: a joystick, a keypad and a scanboard; and three end-effectors: an electric wheelchair (capable to work on the stairs), a manipulator (specifically developed to be located on electric wheelchairs) and an environmental control system. Moreover, three devices with special functions are present: a configuration and control module, a display and a navigator. The integration of the system is based on the M3S (Multiple-Master Multiple-Slave) intelligent interface that allows the users to easily access to multifunctional wheelchair based platforms.

BACKGROUND

Technical aids for motor handicapped people, young as well as elderly, may be divided in: mobility with wheelchairs, autonomy by control of the environment and by use of robotics manipulators, communication of mute people by means of speech synthesiser, vocational workstations.

Until now technical aids has been almost developed in a number of products not compatible with each other. In order to obtain a set of functionality necessary for the autonomy, the disabled person is often compelled to use different devices each with its own man-machine interface and sometimes with overlapping capabilities.

STATEMENT OF THE PROBLEM

The above mentioned vertical approach implies some disadvantages regarding:

- the users that cannot sufficiently use their experience in applying a product when an additional technical aid is required;
- the professionals in re-education, that have to learn the use of a large set of products;
- the agents and consultants (responsible for promotion and training of the products), that have difficulties to promote the totality of products and their selection;
- the technicians, that must interact with different technologies obstructing the integration and the standardisation of the products.

When the connection of input devices and end-effectors in an electric wheelchair environment is needed the M3S [1] represents an efficient method to overcome the limits imposed by the vertical approach.

DESIGN: THE M3S STANDARD INTERFACE

The aim of M3S is both to design a general purpose interface method and a safe, easy to operate and simple to configure integrated control system to be used by disabled and elderly people to control their mobility and their environment. In a M3S system different types of input devices (like keyboards, head pointers, joysticks, etc..) are able to interface to different types of end-effectors (like manipulators, communication aids and wheelchairs).

The M3S general purpose interface is specified in:

- a basic hardware architecture composed by: a CAN bus system [2], a power distribution system, a safety system, a standard connector and a device identification system;
- a bus communication protocol;
- a configuration editor.

The intelligence in the system exists in the controllers of the individual devices and also in the CCM (Control and Configuration Module) which forms part of every implementation of the M3S bus together with a feedback (e.g. a display) device. The intelligence in the CCM deals with the processing necessary to configure the system and the ongoing need to monitor the safety of the system while it is in use.

DEVELOPED PILOT SYSTEM

The pilot system was built up in the contest of the European project IMMeDIAte (Integrated System for Mobility and Manipulation for Disabled Persons).

The system results from the integration of such M3S modules (figure 1):

- the Explorer wheelchair (manufactured by TGR, Italy) capable to navigate on regular surfaces by means of a wheel based locomotion system, as well as on hazardous terrain (including stairs) by means of a track based locomotion system.

- a wheelchair-mounted 6 d.o.f. manipulator (the "MANUS" manipulator, developed by TNO, Delft, and manufactured by Exact Dynamics B.V., The Netherlands). The MANUS is featured by mechanical and control solutions which render the manipulator exquisitely suitable for interacting closely with human subjects [3];
- a navigator (made by CEA, France) consisting in an array of sixteen sensory cells based on infrared and ultrasound sensors dedicated to obstacle detection and avoidance;
- a joystick and a keypad (made by TNO);
- a scanboard (made by FST, Switzerland) allowing touch-screen interface and a variety of operation modes dedicated to the scanning and the selection of a configurable set of buttons;
- a display (made by TNO);
- the James II environmental control system (ECS, made by FST, Switzerland) based on a trainable IR transmitter capable to learn codes within a broad range of frequencies;
- a CCM (made by TNO) performing the actions related to initialisation, configuration, selection, task-control and safety of the whole system.

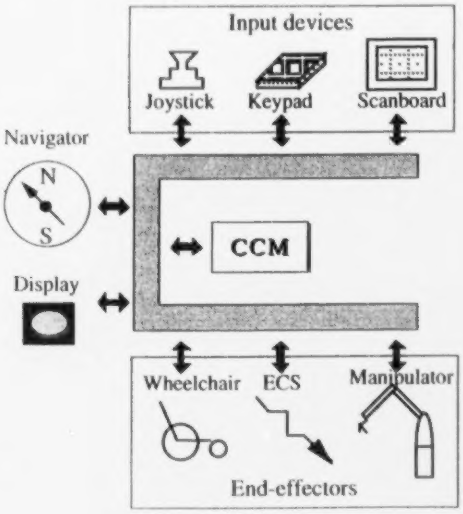


Figure 1
M3S pilot system

Depending on the residual motor capabilities of the end-users the pilot system may be configured to include only the needed equipment. In particular a single input device will allow the user to: scan and select one of the configured functionality; drive the wheelchair (with or without the facilities offered by the navigator); move the manipulator; act on the work space by means of the ECS.

DISCUSSION

Integration, modularity and configuration of a system composed by devices realised by different manufacturers are crucial points to be addressed with the purpose to assure flexibility in the field of systems aimed to increase autonomy of motor handicapped persons. The M3S standard interfacing method allows to integrate in an electric wheelchair platform different kinds of products simply connecting it to the M3S bus and editing the appropriate configuration of the whole system. The assembled M3S pilot system shows the potentiality of this horizontal approach.

REFERENCES

[1] M3S PROTOCOL SPECIFICATION, M3S deliverable WP6, Version 16 April 1993.

[2] Reuss H.-C.: "Controller Area Network (CAN) A Powerful Solution for Fieldbus Applications", Application Note of Philips Semiconductors, Report No. HKI/AN 92 001, July 1992.

[3] Rosier J.C., van Woerden J.A., van der Kolk L.W., Driessen B.J.F., Kwee H.H., Smits J.J., Tuinhof de Moed A.A.: "Rehabilitation Robotics: The MANUS Concept", IEEE Proc. of ICAR '91, pp. 893-898, 1991 June 20-23, Pisa, Italy.

ACKNOWLEDGEMENTS

This work is partially supported by the EC SPRINT project number SP053 named IMMeDIAte.

Prof. Paolo Dario
Scuola Superiore Sant' Anna
Via Carducci, 40
56127 Pisa, ITALY
Tel.: +39-50-883207

BEST COPY AVAILABLE

Concept and Implementation of a Force Feedback Active Joystick

Narayan L. Gehlot, MS and David M. Brienza, Ph.D
University of Pittsburgh
School of Engineering and, School of Health & Rehabilitation Sciences

Abstract

An active joystick with force feedback to indicate obstacles in the environment has been developed. The active joystick is an assistive device for powered wheelchair users who have difficulty maneuvering in confined spaces. Two force feedback concepts intended to assist users have been developed and implemented. The conceptual design, prototype development and prototype testing are presented in this paper.

Background

For persons with marginal ability to control a powered wheelchair using conventional joystick-type input devices, driving a wheelchair can be difficult, dangerous or impossible. For example, a user may have difficulty traveling down narrow corridors, passing through doorways, orienting the chair in a workspace, maneuvering in a confined space such as an elevator, avoiding obstacles, or traveling in a straight path. The aim of the research project described is to improve mobility through the development of a wheelchair control system that assists the user in performing tasks requiring precise control over wheelchair orientation.

The long term goal of this research is to integrate navigational and obstacle detection sensors into a control system that assists the driver of a powered wheelchair in both known—*i.e.* mapped—and unknown environments. The system could also be programmed to execute pre-defined maneuvers such as traversing through doorways or following along walls. Levine *et. al.* have developed a system that uses data from ultrasonic transducers to alter the user's commands from the joystick to assist in avoiding obstacles, following a straight path and safely approaching obstacles. [1,2] Baumgartner has developed a prototype autonomously guided wheelchair control system that follows pre-defined paths using video detection of markers placed within a known environment. [3,4] These two projects represent extremes in terms of the trade-off between global navigation and local obstacle avoidance. Neither of these systems provide feedback to the user indicating how the system is taking over control of the wheelchair. The "smart" wheelchair project at Edinburgh University has also produced a system for assisted control. [5] This design is novel in that it was designed as a training device for severely disabled children. [6] Still other researchers are working toward adapting sensor systems for use in powered wheelchairs. [7,8]

The fundamental technologies and developments identified as essential to a system with the capabilities described herein are (1) wheelchair position and orientation detection and tracking, (2) obstacle avoidance and anti-collision sensors, (3) communications between components located onboard the wheelchair and those located in the environment, (4) obstacle avoidance and guidance algorithms, and (5) user interaction with the control system.

Of the five essential technologies and developments listed, integration of the fourth and fifth elements—obstacle avoidance and guidance algorithms and user interaction with the control system—is most critical to successful development of the proposed system. The first three elements present technological problems which seem readily solvable, given recent advances and cost reductions in sensor systems, radio frequency communications and other related technologies. In contrast, the solution to the problem of shared control, [1] that is, the problem of integrating obstacle avoidance and guidance algorithms with user commands, is unclear. This paper presents a possible solution to this problem through the use of an interactive input device. Specifically, the input device is an active joystick that uses force feedback and variable compliance to both guide the user by suggesting input actions and respond to the user by accepting input commands from his or her actions.

Two philosophies have guided the design process: (1) ultimate control of the wheelchair must remain with the driver and not with the control algorithm, and, (2) mobility efficiency must be maximized. Providing the user with the ability to apply the decisive control input signals distinguishes this wheelchair control system from that of an autonomously guided vehicle. The use of force feedback through the device used to supply input commands—the joystick—is considered a good choice as a medium for interaction between the user and the control system because it does not involve additional sensory inputs such as vision or hearing.

A disability could impair either a person's ability to receive feedback from the environment, for example due to a visual impairment, or a person's ability to supply commands to the system, such as is the case with a neuromotor control impairment. The approach taken in the proposed system could be beneficial to people with either or both types of impairment. Using the force feedback joystick, a wheelchair user's sense of the environment will be enhanced because users will be able to "feel" obstacles through the joystick. They will be aware of the presence of obstacles, whether or not they can see them, through resistance in the joystick to movement in the direction of an obstacle. People who have difficulty controlling a wheelchair due to an inability to produce accurate and reliable input command motions will benefit because actions considered to be undesirable will be discouraged by the joystick's increased resistance to such motions.

Method

In order to execute either of the control schemes subsequently described, the control system must determine if the wheelchair is on a collision course with an obstacle, determine the angle at which the wheelchair is approaching the obstacle and estimate the amount of time left before a collision will occur. Time-to-hit is computed by projecting the current wheelchair direction vector from each of the four corners of the rectangle that describes the boundary of the wheelchair and computing the projected time-to-collision for each corner given the current magnitude of velocity. The minimum of these four calculations is considered to be the time-to-hit. When the time-to-hit is less than the predetermined threshold, the present course is flagged as a collision course. Two algorithms have been developed—passive assist and active assist—as described below.

Passive Assist: The essence of the passive assist control algorithm is to aid the driver in avoiding collisions with obstacles by discouraging steering inputs which would tend to steer the wheelchair into an obstacle. This is accomplished by increasing the stiffness of the joystick in the direction that would tend to steer the wheelchair into the obstacle. This method is considered passive because it requires the driver to initiate a steering command before the joystick adjustment is activated. If the wheelchair is steered in a direction perceived to be safe—*i.e.* obstacle free—no feedback is given. If, on the other hand, the driver steers the wheelchair toward an obstacle, the proportional gain for the joystick on the steering DOF is increased, making it stiffer.

Active Assist: The active assist method controls the neutral point of the steering DOF of the joystick according to the location of obstacles in the path of the wheelchair. That is, if a collision course is detected, a force is applied along the joystick steering DOF which would tend to steer the wheelchair away from the obstacle. The magnitude of the force is dependent upon the computed time-to-hit, the angle between the wheelchair velocity vector and the line defining the obstacle and the position of the joystick along the steering DOF. In this case, if the user does not resist the force applied by the joystick that would tend to steer the wheelchair away from the obstacle, the turning action would commence and continue until the wheelchair was no longer on a collision course. If a user is capable of decoupling his or her steering and speed input forces, it is possible, in effect, for the user to allow the control system to steer the wheelchair away from obstacles while the user controls the speed of the wheelchair.

Test and Evaluation Procedures: The purpose of the initial testing and evaluation is to determine if the proposed active assist and passive assist control concepts satisfy the design goals for the system. Toward this end a prototype evaluation system has been developed as shown in Figure 1. A test environment was created which simulated boundaries and obstacles. The operating parameters (i.e. the proportional gain) for the actuator controlling the speed degree of freedom is not manipulated by the control algorithm. The wheelchair is tracked through the laboratory environment by starting from a known position and orientation and monitoring rotations of the rear wheels of the wheelchair. Position and direction are updated at each sampling interval. The method and theory of direction and position computation is

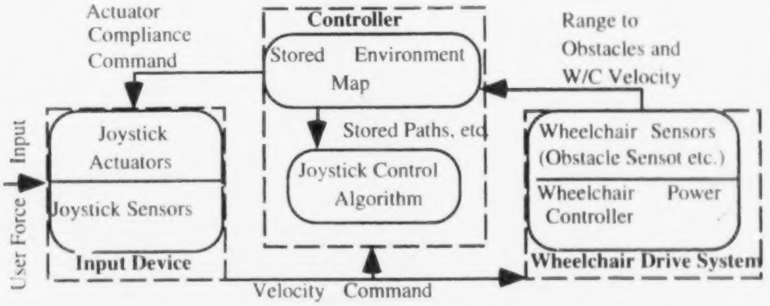

Actuator Compliance Command
Controller
Stored Environment Map
Range to Obstacles and W/C Velocity
User Force Input
Joystick Actuators
Joystick Sensors
Input Device
Stored Paths, etc.
Joystick Control Algorithm
Wheelchair Sensors (Obstacle Sensot etc.)
Wheelchair Power Controller
Wheelchair Drive System
Velocity Command

Figure 1. The test setup developed for the initial testing..

based on the work presented in Hongo *et. al.* [9].

Results

Laboratory testing was performed to assess the accuracy of the positioning and orientation monitoring system. The wheelchair was driven along known paths of approximately 20 ft. while actual position and orientation measurements were compared to computed measurements. Results indicated that the position could be tracked with an accuracy and repeatability of approximately ±0.25 inches and orientation could be determined with an accuracy and repeatability of ±0.5 degrees. All error is accumulative, hence longer courses will result in greater errors. To evaluate the proposed control schemes, courses involving common maneuvers such as traveling and turning in a narrow corridor, negotiating a doorway, making a close approach to an object, and turning around in a small area will be created in a laboratory environment. The total length of these courses will be restricted to avoid the effects of accumulation of tracking errors.

Discussion

The control algorithms have been designed to be simple and to apply as generally as possible to a wide range of driving scenarios without defining many special circumstances and strategies to assist in these circumstances. This approach is likely to avoid problems associated with complicated mode switching for different situations and enhance the intuitiveness of the joystick control. However, it is recognized that certain situations will not be handled very well by either strategy and will need special consideration. For example, if a wheelchair is traveling close to and parallel to an obstacle, steering inputs which would steer the wheelchair into the obstacle should be discouraged. However, because the resistive force depends upon the angle between the wheelchair velocity and the line defining the obstacle, the reaction of the joystick would likely come too late to assist the driver in avoiding a collision. This circumstance could be handled by adding a factor to the steering resistance force which depends upon obstacles detected perpendicular to the wheelchair direction vector. Future work needs to reduce power consumption by AJS to make it practical and not put undue stress on the batteries. Single board computers for on-board processing will be needed for signal acquisition and processing in the actual implementation.

References

[1] Levine S. NavChair control system for automatic assistive wheelchair navigation. *Proceedings of the RESNA 1990 Annual Conference*. Arlington, Virginia: RESNA Press, 1990; 10.

[2] Jaros L, Bell D, Levine S, Borenstien Y. NavChair: design of an assistive navigation system for wheelchairs. *Proceedings of the RESNA 1993 Annual Conference*. Arlington, Virginia: RESNA Press, 1993; 13.

[3] Baumgartner E T. *An Autonomous Vision-Based Mobile Robot*. South Bend, Indiana: University of Notre Dame, 1992.

[4] Baumgartner E T, Yoder J-D. An automatically-guided powered wheelchair for the severely disabled. *Proceedings of the RESNA 1994 Annual Conference*. Arlington, Virginia: RESNA Press, 1994; 14: 350-352.

[5] Nisbet C I. The evolution of a modular augmentative mobility system. *Proceedings of the RESNA 1994 Annual Conference*. Arlington, Virginia: RESNA Press, 1994; 14: 301-303.

[6] Nisbet C I. Mobility and mobility training for severely disabled children: results of the "smart" wheelchair project. *Proceedings of the RESNA 1994 Annual Conference*. Arlington , Virginia: RESNA Press, 1994; 14: 341-343.

[7] Hoyer H, Hoelper R. Intelligent omnidirectional wheelchair with a flexible configurable functionality. *Proceedings of the RESNA 1994 Annual Conference*. Arlington Virginia: RESNA Press, 1994; 14: 353-355.

[8] Thomas D. A robust, self-diagnosing methodology for application to smart wheelchairs. *Proceedings of the RESNA 1994 Annual Conference*. Arlington, Virginia: RESNA Press, 1994; 14: 466-468.

[9] Hongo T, Arakawa H, Sugimoto G, Tange K, Yamamoto Y. An automatic guidance system of a self-controlled vehicle. In: Cox I J & Wilfong G T (eds) *Autonomous Robot Vehicles*. New York: Springer-Verlag, 1990; xxvi: 32-37.

Acknowledgment

This research is support by the U.S. Department of Education, National Institute on Disability and Rehabilitation Research, Grant#H133E0005.

Narayan Gehlot, MSEE, Ph.D. (candidate) EE
University of Pittsburgh
School of Engineering
School of Health & Rehabilitation Sciences
915 William Pitt Way, Pittsburgh, PA 15238
Phone: 412-826-3138, Fax: 412-826-3143

A FLEXIBLE JOYSTICK HANDLE

Andrew J. Brulé, M.A.Sc., P.Eng.
Jennifer S. Law, B.Sc. O.T.
Sunny Hill Health Centre for Children, Vancouver, Canada

ABSTRACT

Clients with high tone and/or athetoid movements can cause a great deal of damage to the proportional joysticks of modern power wheelchairs. Modern proportional joysticks (especially the gimbals) are not designed to withstand high forces and therefore break requiring expensive repairs. A possible versatile low-cost solution to such a problem is a flexible joystick handle which will deform under the high loads protecting the gimbal from the high forces.

INTRODUCTION

Children with abnormally high muscle tone have a dilemma. They require powered mobility to be as independent as possible but are too rough for most modern proportional joysticks. Many of these mechanisms are broken as a result of the excessive forces exerted by the child's extensor spasm. This leads to a great deal in repair costs.. Tables 1 and 2 illustrate this problem with only two of the clients followed at this centre alone. Client #1 has damaged nine joystick assemblies in thirty months and six in 1994 alone for a total cost of $2351.00 (CND) plus labour. Client #2 has damaged four joystick assemblies in twenty-four months at a cost of $748.00 plus labour (CND). These clients have limited gross and fine motor control and would benefit greatly from the independence of wheeled mobility. However, because of their spasticity, they are unable to effectively wheel themselves and therefore require powered mobility. To best control a powered wheelchair they require a "T" grip to grasp the joystick handle. Due to their poor motor control they are unable to release the joystick "T" handle during a spasm and can damage the joystick. At a cost of $187.00 (CND) per gimbal it was evident that a low cost solution would have to be developed.

Table 1 - Work Records on Client #1 Joystick
(Purchased Invacare Arrow XT, July 1991)

Date	Work	Cost (CND)
April 1992	Rebuilt Gimbal	labour
October 1993	Replaced Gimbal	$187.00 + labour
November 1993	Replaced Housing	labour
February 1994	Replaced Gimbal	$187.00 + labour
February 1994	Replaced Gimbal	$187.00 + labour
February 1994	Replaced Gimbal	$187.00 + labour
August 1994	Replaced Joystick	$708.00 + labour
August 1994	Replaced Joystick	$708.00 + labour
September 1994	Replaced Gimbal	$187.00 + labour
	Total	$2351.00 + labour

Table #2 - Work Records for Client #2 Joystick
(Purchased Invacare Arrow 5M, January 1992)

Date	Work	Cost (CND)
March 1992	Replaced Gimbal	$187.00 + labour
February 1993	Replaced Gimbal	$187.00 + labour
January 1994	Replaced Gimbal	$187.00 + labour
April 1994	Replaced Gimbal	$187.00 + labour
	Total	$748.00 + labour

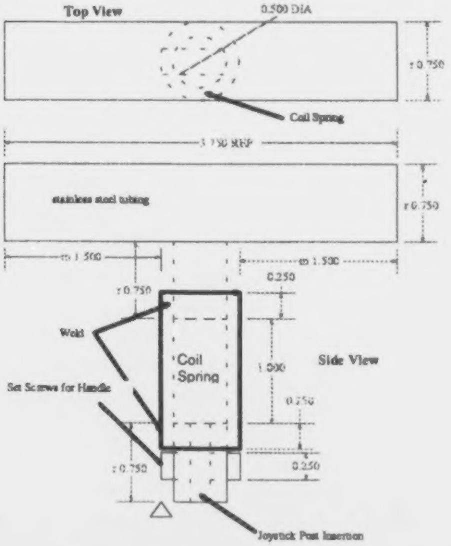
OPTIONS

A micro-switch joystick can be made stronger and more durable than a proportional joystick but are cognitively and functionally more difficult to operate. The Hugh MacMillan Centre has developed a heavy duty proportional joystick which is costly ($1995.00 CND) and is not, at present, compatible with all wheelchair controllers.

One option was a breakable joystick handle, a "sacrificial" handle. When stressed enough to cause damage to the gimbal, the handle would break thereby saving the more costly joystick hardware, much like a 10¢ fuse blowing to protect a $1000 component. Unfortunately, sometimes the $1000 component blows in order to protect the 10¢ fuse. Determining the proper forces required to save the gimbal would be tricky. Also, once the handle has been broken, the client has difficulty operating the chair. It would be desirable to allow the handle to "break" but reform after the spasm has ended thereby enabling the client to continue to operate the chair: the concept of the flexible joystick handle.

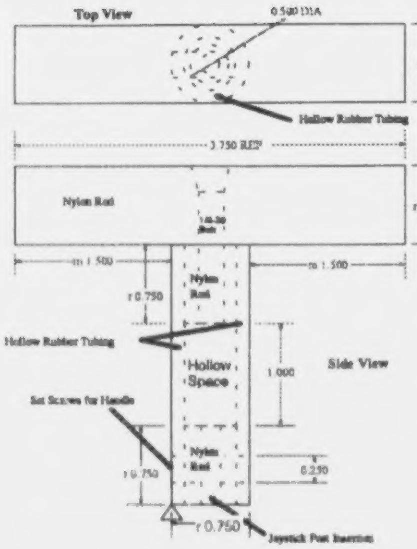
DESIGN

Initial designs consisted of a steel coil spring with stainless steel tubing welded on both ends as the vertical bar and the horizontal bar welded to one end (see Figure 1). Two problems were encountered with this design. First, welding the steel spring to stainless steel was tricky because once you heat the spring steel to weld it, it usually loses its elasticity. The spring material could be heat treated again but this would be costly. These handles became brittle at the welds and broke. Secondly, a coil spring when flexed laterally will create "pinch points" to catch the skin etc.... For these reasons this design was abandoned in favour of a flexible rubber tubing (i.e. heavy duty rubber hose) as the vertical member and a nylon rod as the horizontal member (see Figure 2). The materials are low cost, easily obtained, durable and good for manufacturing.



Flexible Joystick Handle #1
Andrew Brulé, P.Eng.
Sunny Hill Health Centre for Children
December 8, 1994

Figure 1 - Flexible "T" Grip with Coil Spring



Flexible Joystick Handle #2
Andrew Brulé, P.Eng.
Sunny Hill Health Centre for Children
December 8, 1994

Figure 2 - Flexible "T" Grip Joystick Handle

EVALUATION

The flexibility of the rubber hose is thermally sensitive and may develop small cracks in extremely cold temperatures but this has not been encountered in the prototype. Client #2 has been using the prototype for the last six months and has not encountered any problems and has not damaged any other joystick assemblies. Hugh MacMillan reports that for some clients the flexible joystick made it difficult to control the direction of the chair and a heavy duty proportional joystick was the only option[1]. This has not been found in our client.

One unexpected benefit has been observed during this test phase. During an extensor spasm that may cause damage to the joystick mechanism the thumb may be trapped below the handle of the rigid "T" joystick and the fingers in extension on top. This makes it difficult to

---

[1] Personal conversation with the "Interfaces Department" of the Hugh MacMillan Centre, 350 Rumsey Rd., Toronto, Ontario, CANADA, M4G 1R8, December 10, 1994.

BEST COPY AVAILABLE

release the handle. The flexible joystick allows the user to more easily release the handle because it can also flex torsionally allowing the handle to "rotate" out of the hand releasing the thumb from under the handle.

CONCLUSIONS

This is a low cost and versatile alternative to a heavy duty proportional joystick and a more functional option than resorting to a micro-switch joystick. This handle may prolong the service life of the gimbals for clients with strong athetoid movements.

ACKNOWLEDGEMENTS

The authors would like to thank Sunny Hill Health Centre for Children for their support in the preparation of this product and document.

Andrew Brulé, M.A.Sc., P.Eng.,
Rehabilitation Engineer
Sunny Hill Health Centre for Children
3644 Slocan St.,
Vancouver, British Columbia, CANADA
V5M 3E8

A POLYVALENT CONTROL INTERFACE

Yves Lozac'h, Lucie Tremblay
INSTITUT DE READAPTATION DE MONTREAL
Centre de recherche

ABSTRACT

A new robust and proportional control interface has been developed for severely disabled people. Designed around a contactless inductive joystick this interface utilizes a flexible geometry of operation which is well-suited for the adjunct of simple and ergonomical adaptations. These characteristics and the flexibility of this interface should allow the user to match a greater number of anatomical movements and thus to adapt to different control sites. Designed primarily for wheelchair control this proportional interface can also be used to access communications and environmental control devices. The first phase of the clinical evaluation is now completed for several potential control sites and the preliminary results are encouraging.

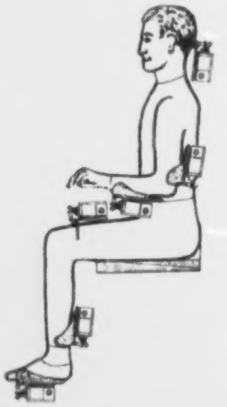


Figure 1
Potential control sites envisaged

BACKGROUND

Technological progress related to powered wheelchairs and to their control interfaces have already played an important role in the rehabilitation of the severely disabled people. The function of the control interface is to convert a biological activity into an electrical signal suitable for the control of the desired action. The quality of the control obtained is then directly related to the qualities of the interface and to the close ergonomical coupling of this interface with the user. From the view-point of the disabled user, the control interface is the indispensable link between him and the assistive devices he may require. Depending-upon whether the signal is on-off or continuously variable, interfaces are divided into two categories. The on-off and the proportional control categories the joystick is a well known example of the latter. Although proportionally controlled interfaces offer several benefits to the disabled user they are often underutilized and not always well-differentiated from the on-off types by all clinical personnel. The reasons for their underutilization may be due to the wide range of differences among disabled people and consequently the great degree of customization required to match these interfaces to them (1). There are at least two major advantages of the proportional approach:

a) When used with a motorized wheelchair, it will smoothly control both the speed and the steering of the chair as a function of the amplitude of the biological activity or the voluntary movement generated by the disabled person. This proportional control is also the only way to obtain a close coupling between the driver and their vehicle.

b) Several different choices can be attained from a single movement. This is particulary important when the proportional interface is used with a communication aid or an environmental control system.

Besides the need to privilege a proportional approach whenever a functional gain can be expected by the disabled user, there is also a need for proportional control when the interface must be to ergonomically and carefully matched to the person's abilities. This has been our goal throughout our interface development program and it has led to the following proportional control realisations:(2-3-4-5)

1) A head control interface designed in 1973. The technology for this control system was transferred to Everest and Jenning in 1976 and now is available from them and from two other major american companies.

2) The knee control interface designed in 1979 for the persons who have severe motor impairment due to cerebral palsy (C.P.). Controlled by the adduction and abduction of both knees this control interface, used by many of our clients this is still produced at our rehabilitation center.

3) The highly sensitive control interface designed in 1979 for individuals who have limited and weak residual movements such as those related to muscular dystrophy. Operated by finger or tongue movements this interface requires a high level of ergonomic customization and consequently has only been produced on demand by our center.

4) The sliding disk control interface designed in 1986 for persons who have (C.P.). Its operation calls for the translation of a control disk which has been used at the level of both the foot and the elbow. This interface is now produced and is available from or canadian a company "Orthofab".

OBJECTIVES AND DESIGN CRITERIA

On the basis of clinical results and with the experience acquired during the development of the realisations listed above, we have decided to develop and evaluate a new proportional control interface which we believe is potentially more flexible and polyvalent than the previous versions. Hopefully, this interface will complement or replace some of the older versions and will expand the range of possibilities for access and control to a larger number of disabled individuals. Based on a modular concept, the control interface operates on the principle of a pivoting and rocking motion of a paddle plate. The plate can be easily adapted to accomodate a variety of ergonomical adaptations permitting a variety of operation's modalities and the capacity to interface with broader range of anatomical movements. This design approach offer additional advantages which are: firstly the possibility for the clinician to experiment with a client one or more control site without the need to buy new interfaces. This flexibility is particularly useful with C.P. subjects for whom the decision about the selection of the best control site is often difficult. Secondly, depending on the control site selected, this interface can be controlled either bidirectionally like a joystick or unidirectionally like a head control interface. Thirdly, the polyvalence will also decrease the inventory of control interfaces now needed in a rehabilitation center.

The utilisation polyvalence represent the first design criteria of the control interface. As shown by fig. 1, several potential control site have been envisaged.

The other design criteria are the following:

- Ergonomically easy to match to the physical abilities of the user.
- Robust and reliable.
- Stable and safe.
- Usable whenever applicable on the right or left side.
- Minimally obtrusive in both terms of dimensions and appearance.
- Adaptable on most powered wheelchairs.
- Producible at a reasonable cost.

CLINICAL EVALUATION

A one-year project has permitted the developement and production of a prototype of the new proportional interface. During this period the production was followed by a preliminary clinical evaluation on three control sites out the six envisaged. Used as a head control, the interface has been comparatively evaluated by three candidates. When used as a knee control or forearm control interface, a single evaluator has been tested with each body segment.

The evaluation as a head control interface has been carried out by a limited group of individuals who had a traumatic gradriplegia. The testing of all the other control sites has been or will be carried out by candidates who have C.P. and for whom the evaluation, the ergonomic installation and matching of the control interface are much more complex than with the first group of users.

THE PRELIMINARY CLINICAL RESULTS:

The results to date will be presented at the conference and the new control interface will be displayed. Some pertinent observations concerning the initial tests, particularly when used as a head control system are that the operation modality of the new interface is to some extent different from the older version for which the turning action was obtained from the rotation of the neck. For the new model turning is obtained from the lateral bending of the neck. The first results of the evaluations have shown that this new approach is prefered by the evaluators since it allows a sharp turning rate in both the forward and reverse speeds. With the older versions a sharp turning rate could only be obtained in the reverse speed which required frequent switching actions when manoeuvring in a confined area. Other results indicates that the cosmetics and the relative obstruction of the user have been improved and are well-appreciated by the evaluators. Two other control sites, the knee and the forearm have also been partially evaluated. With the knee, the evaluator selected was a person who has a severely disabling C.P. and who has been equipped for many years with the older version of the knee control interface. Following a few training sessions, the candidate was able to control his chair. However probably because of the long experience with his old control system he still felt more confident with it. The last control site tested was also done by a client who has C.P. He is actually a safe user of a modified hand controlled joystick interface but for the time being he has just tried and successfully used the interface once. This partial result seems to indicate that the forearm version can probably be

used by C.P. candidates who are more severely disabled than this first evaluator.

CONCLUSION:

The premilinary results obtained from the first phase of the clinical evaluation are encouraging. A second and a more elaborated clinical evaluation is now required in order to verify these results and to determine the degree of polyvalence which can be associated with this new control interface.

ACKNOWLEDGMENT

This work has been supported by grand (RRRMOQ) reference 1992-P9 from the "Réseau de recherche en réadaptation de Montréal et de l'Ouest du Québec"

References:

1. Gaddis, E.L. (1981) New developments in proportional interface research , 4th annual conf. on Rehabilitation Engineering, Whashinton DC: 72-74.

2. Lozac'h, Y., Gosselin, G., Sherman, E.D., Gingras, G., Ritchuk, M., New head control for quadriplegic patients. Bulletin of prothetics research: 151, Spring 1975.

3. Lozac'h, Y., Glazer, P. Knee controlled interface for cerebral palsied patients. Fifth annual Conference on Rehabilitation Eng. 122, Houston, Texas, 1982.

4. Lozac'h Y. Les signaux biologiques et les interfaces de commandes. La réadaptation ... entre nous! Actes du 1er Congrès québécois en réadaptation fonctionnelle: 194, Montréal, Nov. 1985.

5. Lozac'h Y., Valiquette, C., Lacoste, M., "A sliding disk control interface for an electric wheelchair". 13 th Can. Med. Biomed. Eng. Conference: 123-124, Halifax 1987.

Yves Lozac'h
Centre de recherche
Institut de réadaptation de Montréal
6300 Darlington
Montréal, Québec
Canada
H3S 2J4

Tél.: (514) 340-2078
Fax.: (514) 340-2154

WHEELCHAIR RELATED ACCIDENTS AND MALFUNCTIONS

Rory A. Cooper, Ph.D. and Helen McGee
Human Engineering Research Laboratories
Dept. Rehabilitation Science and Technology
Div. Physical Medicine and Rehabilitation
University of Pittsburgh
Research Service
Veterans Affairs Medical Center
Highland Drive, Pittsburgh, PA

Abstract

The ANSI/RESNA Standards Committee has been responsive to safety issues revealed by consumers, regulatory agencies or research. Frequency of failures, accidents, and injuries can provide valuable insight into the necessity and adequacy of wheelchair standards. This study examined US FDA Medical Device Reporting System (MDRS) records from 1975-1993 to investigate whether there are trends or patterns with wheelchair failures and accidents. There were a total of 705 reports filed during the period reviewed. Component failures accounted for 55 percent of all reported incidents. Standards should help to minimize component failures through static, impact and fatigue strength testing.

Background

The needs and desires of wheelchair users are diverse and manufacturers have developed a wide variety of products to meet consumer's needs. However, with a wide variety of products, some of which are quite sophisticated, consumers and clinicians often experience difficulty making the proper selection and specification. In 1979, the ANSI/RESNA Wheelchair Standards Committee was formed to develop standards for testing and comparing wheelchairs. The ANSI/RESNA Wheelchair Standards are technical and require some clarification to be applied by consumers and clinicians in the selections of wheelchairs. Short courses, and books have been developed to support this process [1]. Wheelchair standards are used to help assure that products are of reasonable quality, products are safe, and to encourage clear communication among consumers, clinicians and manufacturers.

The ANSI/RESNA Wheelchair Standards Committee has been responsive to safety issues revealed by consumers, regulatory agencies or research. Static and dynamic stability of manual and power wheelchairs have been areas where research has revealed the need to revise standards [2-4]. An estimated 26,000 wheelchair users in the United States experience serious wheelchair-related accidents each year [2]. Tips and falls constitute the majority of the approximately 50 fatal accidents each year. Theoretical models, experimental models, and test methods have been developed to ensure safe and effective wheelchair mobility as related to stability.

Unmat and Kirby examined 2,066 nonfatal wheelchair-related accidents reported to the US Consumer Product Safety Commission National Electronic Injury Surveillance System (NEISS) between 1986 and 1990 [3]. They estimated that about 36,000 accidents occurred each year which required a visit to a hospital emergency room. The majority of injuries were contusions and abrasions (33%), lacerations (28%), fractures (20%), and sprains/strains (10%). Hospitalization was required in 12 percent of cases.

Electromagnetic interference, in the ambient environment, has recently been revealed as posing a possible risk to power wheelchair and scooter users [5]. Witters and Ruggera report that there had been several incidents, in recent years, related to uncontrolled or undesired movement of power wheelchairs and scooters which strongly suggest electromagnetic interference [5]. Concerns about EMC related safety of power wheelchairs and scooters has resulted in the ANSI/RESNA Wheelchair Standards Committee developing a draft EMC standard.

Frequency of failures, accidents, and injuries can provide valuable insight into the necessity and adequacy of wheelchair standards.

Research Question This study examined the US FDA Medical Device Reporting System (MDRS) records from 1975-1993 to investigate whether there are trends or patterns with wheelchair failures and accidents. It was hypothesized that MDRS records may indicate areas which require standards and components of the standards which require improvement.

Methods

MDRS records were requested from the US FDA through the Freedom of Information Act. The keyword wheelchairs was used for the database search. Wheelchairs is used to code data for wheelchairs and associated products (e.g., lifts, seating systems). Information is provided to the FDA as required by the Medical Device Reporting Regulation. Reports are submitted without verification of the information. The

FDA may and does examine cases which it deems worthy. The MDRS does not necessarily imply admission of a malfunction or that a device was causally connected to injury or death.

MDRS events are classified by Report Type. Report Types include: Malfunction, Device Experience, Serious Injury, and Death. The MDRS provides a description of the incident, and in some instances Closeout Information (i.e., results of investigations or known cause). We examined the number of reported incidence per year and the seasonal frequency.

Incidence were divided into EMC, other, stability, user error, no reported cause, and component failure. EMC was defined as an incident that based upon the report description was consistent with an EMI response. Other was used to place incidents that were explained in the report, but did not fit into one of the other categories (e.g., wheelchair user was pinched by vehicle lift). Stability was used to describe tilting and tipping accidents, all directions were lumped together (e.g., anterior, posterior, and lateral). User error was used to describe incidents that were related to users behavior (e.g., burning cigarette, running into something). No reported cause was used when there was insufficient data to categorize the incident. Component failure was used to describe incidence which could possibly be attributed to the breakage or malfunction of a component or sub-assembly.

The investigators read the entire MDRS report. Each of the investigators categorized the data independently. Upon complete categorization of the data, results were compared. Each incidence with a categorization discrepancy was rereviewed and discussed and then assigned a category based upon consensus. Data were then entered into a database by one individual, and then verified by another.

Results

There were a total of 705 reports filed during the period reviewed. Manual wheelchairs accounted for 172, powered wheelchairs 202, scooters 270, wheelchair lifts 26, and other 33. Incidents were distributed over the entire year with Fall (153) and Winter (158) receiving fewer reports than Spring (184) and Summer (210). There was an upward tendency in the number of reports each year, see Figure 1. However, the maximum number of reports occurred in 1987 with 138.

Component failures accounted for 55 percent of all reported incidents. No known cause was the next most frequent (142), followed by user error (104), stability (38), other (27), and EMC (4). Serious injury was the most common reason for reporting an incident.

Discussion

The increasing reporting trend can likely be attributed to greater awareness of the MDRS and to the proliferation of personal computer systems which simplify automated reporting. Clinicians, manufacturers, and distributors are also probably becoming more aware of standards and their impact on improving product quality which may make them more apt to report incidents.

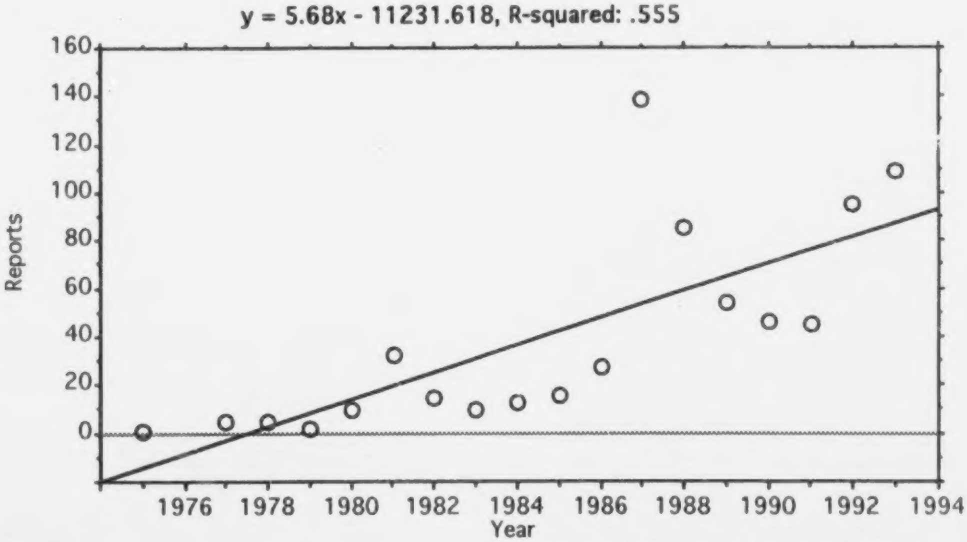
There appears to be some seasonal variability. Spring and Summer seasons are times when people tend to be more active. Increased activity could expose people more to environmental hazards, and place greater stress on wheelchairs.

Having component failures represent 55 percent of the reported incidence generates some concern. Standards should help to minimize component failures through static, impact and fatigue strength testing [1]. Electrical components should also be safer due to power and control tests [1]. The high incidence of reports on component failures may be a reflection of some manufacturers not applying the standards, and clinicians not demanding products which comply with ANSI/RESNA Standards. A number of the failures involved components and accessories for wheelchairs (e.g., armrests, legrests). This may be an indication that the standards need to address these areas more closely. Currently, armrests only receive static strength testing. There are no ANSI/RESNA Standards for accessories (e.g., laptrays, specialized seating systems).

The number of reports with no known cause is disturbing. Greater training of professionals filing the reports and follow-up on more of the most serious incidents could help to reduce this number. Sometimes, failures within controllers or input devices (e.g., joysticks) are difficult to diagnose and may go reported as of unknown origin.

User error accounted for a substantial number of the reported incidence. This should be of particular significance to educators and clinicians. The risk posed to consumers and their associates can be reduced by developing adequate mobility skills, and matching each individual with the appropriate technology. Consumers, clinicians, and educators should strive to reduce user error related accidents. One of the more frequent causes of serious injury due to user error were fires related to cigarettes. This requires educating consumers on healthy lifestyles.

Our review of the reports indicates that four possible incidence of EMC causing a power wheelchair to behave erratically may have occurred. Although four is not a large number when compared to the 390 for component failures, it does indicate that there may be some justification, especially because of the potential for serious injury, for the development of an EMC Standard for Power Wheelchairs and Scooters. With the increased proliferation of solid-state microelectronics susceptibility to EMC could become a more significant problem without a power wheelchair standard.



References

1. Axelson PW, Minkel J and Chesney D, A Guide to Wheelchair Selection: How to Use the ANSI/RESNA Wheelchair Standards to Buy a Wheelchair, Paralyzed Veterans of America, Washington, D.C., 1994.
2. Majaess GG, Kirby RL, Ackroyd-Stolarz SA and Charlebois PB, Influence of Seat Position on the Static and Dynamic Forward and Rear Stability of Occupied Wheelchairs, Arch Phys Med Rehabil, 74:977-982, 1993.
3. Unmat S and Kirby RL, Nonfatal Wheelchair-Related Accidents Reported to the National Electronic Injury Surveillance System, Am J Phys Med & Rehabil, 73:163-167, 1994.
4. Kirby RL, Ackroyd-Stolarz SA, Brown MG, Kirkland SA and MacLeod DA, Wheelchair-Related Accidents Caused by Tips and Falls among Noninstitutionalized Users of Manually Propelled Wheelchairs in Nova Scotia, Am J Phys Med & Rehabil, 73:319-330, 1994.
5. Witters DM and Ruggera PS, Electromagnetic Compatibility (EMC) of Powered Wheelchairs and Scooters, Proc. 16th IEEE-EMBS Conf., Baltimore, MD, 16(2):894-895, 1994.
6. Bassen H, Ruggera P, Casamento J and Witters D, Sources of Radiofrequency Interference of Medical Devices in the Non-Clinical Environment, Proc. 16th IEEE-EMBS Conf., Baltimore, MD, 16(2):896-897, 1994.

Acknowledgment

This work was partially supported by the Carnegie Mellon University Undergraduate Research Opportunity Program, Paralyzed Veterans of America, and Rehabilitation Engineering and Research Center on Technology to Improve Wheeled Mobility, Nation Institute on Disability and Rehabilitation Research, HE133005. The authors are grateful to Peter Axelson for his assistance.

Rory A. Cooper, Ph.D.
Human Engineering Research Laboratories
Veterans Affairs Medical Center
7180 Highland Drive, Pittsburgh, PA 15206
TEL: 412-365-4850
FAX: 412-365-4858

LOW BACK PAIN AND WHOLE BODY VIBRATION EXPOSURE FOR WHEELCHAIR USERS

Gerald Weisman, M.S. and Dryver R. Huston, Ph.D.
Vermont Rehabilitation Engineering Research Center
University of Vermont Burlington, Vermont

ABSTRACT

Low back pain is a common problem among people with disabilities, particularly those who use wheelchairs. The whole body vibration of vehicle operators has been linked to high rates of low-back pain complaints. This paper examines the possibility of similar occurrences in wheelchair operators by measuring actual vibration levels in a wheelchair, and comparing with the ISO 2631 standards. In certain circumstances the vibration levels are found to be too high for long-term exposure and comfort

INTRODUCTION

Low back pain is a common problem among people with disabilities, particularly those who use wheelchairs. "Ride quality" of manual and powered wheelchairs has been a topic of discussion and research for some time. The recommendations of the Wheelchair III Workshop (1) held in 1982 included a statement that, "the ride quality of the equipment is considered to be a research item." However, at the time it was acknowledged that ride quality was ill defined and "research and development effort is needed to provide good safety and comfort to the user." McLaurin, in the Wheelchair IV Workshop (2) in 1988 identified measurable factors of ride quality as vibration, acceleration, jerk, noise, bucking and stability. He noted the natural frequency for a person in a wheelchair in the order of 5 to 6 Hz. In the same report, Thacker identified the potential application of ISO 2631 Whole Body Vibration standards to the vibration experienced by wheelchair users. Thacker suggests the average daily exposure time for a wheelchair user is 4 - 8 hours. While whole body vibration has been identified as contributing to "ride quality" for wheelchair users, no one has suggested that this vibration may be a contributing factor to low back pain experienced by wheelchair users. Numerous studies have determined that there may be some correlation between whole body vibration exposure and low back pain (3), (4), and (5). The most commonly reported effects noted in the literature are low back pain, early degeneration of the lumbar spinal system and herniated lumbar disc. However, no firm causal relationship has been established (6). Hansson and Helm (7) have indicated that whole body vibration is involved with pathophysiological aberrations in the spine. Seidel et. al (8) suggest the possibility of fatigue failures at the endplates of the lumbar vertebrae after intense long-term exposure to whole body vibration.

It seems reasonable to assume that the vibration experienced by wheelchair users may contribute to low back pain and other associated problems. We have conducted a pilot study to determine the level of vibration experienced by a wheelchair user. An inexpensive yet robust field vibration acquisition, data analysis and dosage recording system has been developed that makes the recording and analysis of vibration data easy and efficient.

METHODS

The prototype data acquisition system consists of a portable PC and integrated circuit accelerometers as the transducers. The vibration data are acquired and analyzed in pseudo-real-time. The data are then converted to an equivalent dosage by frequency domain conversion and comparison with ISO 2631/1 standard.

A 50 MHz 486DX laptop computer was used for this system. Power for the system is supplied by the wheelchair batteries. A custom adapter from the laptop supplies power to the accelerometer amplifiers. Three micro-machined integrated circuit accelerometers were selected for use as a triaxial transducer primarily because of performance, cost and geometry. They provide DC response, are relatively inexpensive and in surface mount configuration are very small. This was obviously a concern as the operator had to sit on the triaxial transducer pack. Simple temperature-compensated quad OP-amp amplifier circuits for accelerometers were made. Signals from the amplifiers are then passed to a PCMCIA-type data acquisition card. A sampling frequency of 250 Hz was used to satisfy Nyquist criteria for a range of frequencies from of 1 to 120 Hz in accordance with ISO 2631.1. 1024 point Fast Fourier Transforms (FFTs) were used to convert the time histories to the frequency domain.

The vibration characteristics of a commonly used powered wheelchair were determined using a commercially available vibration assessment system and compared to ISO 2631/1 standards (9). The ISO standard defines and presents numerical values for limits of exposure for vibrations transmitted from solid surfaces to the human body in the frequency range 1 to 80 Hz. Criteria for preserving comfort, working efficiency, and safety and health are named "reduced comfort boundary," "fatigue-decreased proficiency boundary," and "exposure limit" respectively. These limits are defined for the different purposes for which the standards may be used. For example, the "fatigue-decreased proficiency" limit would be used in relation to maintaining the efficiency of a vehicle or equipment operator while the "reduced comfort" limit might be used to define the vibration exposure to assure passenger comfort in transportation systems. The ISO standards do not specifically address the potential biomechanical and pathophysiological effects of vibration on the spine.

The "fatigue-decreased proficiency boundary" specifies "a limit beyond which exposure to vibration can be regarded as carrying a significant risk of impaired working efficiency in many kinds of tasks, particularly those in which time-dependent effects (fatigue) are known to worsen performance as, for example, in vehicle driving." The maximum safe exposure, or "exposure limit," is determined for any condition of frequency, duration and direction, by doubling the values allowed for the criterion of fatigue-decreased proficiency. The "reduced comfort boundary," derive from various studies conducted for the transport industries, is approximately one-third of the corresponding levels of the fatigue-decreased proficiency boundary.

PROTOCOL

Using a commonly-available powered wheelchair, data were collected under a variety of conditions for a single user. The wheelchair control system was set up using the manufacturer's standard values for such parameters as speed, acceleration, sensitivity and braking. Conditions tested included high (H) and low (L) speeds, sling (G) and solid (D) seat, and indoor (I) and outdoor (O). The sling seat was the seat provided by the manufacturer. The solid seat consisted of a 3/4" plywood fit between the seat rails. No wheelchair cushion was used. The indoor condition consisted of a clinic hallway carpeted with low pile industrial carpeting. The outdoor condition consisted of a gravel parking lot. A test run was also made on a typical concrete sidewalk at high speed using the sling seat (Sidewalk). Data were collected for a total of 5 minutes for each condition. The vertical acceleration level averaged over the measurement time was compared to the ISO standard.

RESULTS

Representative samples of raw data in the time and frequency domain are shown below. Table 1 illustrates the results of the pilot testing. Results are reported as time limits as defined by the ISO 2631 standard.

Table 1.

Cond.	Avg,. accel. (m/ s^2)	Red. Comf. Lim.(h)	Fatigue Dec. Pro.(h)	Exposure Lim.(h)
I-L-G	0.181	2.5	16	24
I-H-G	0.354	1	4	16
I-L-D	0.247	2.5	8	24
I-H-D	0.366	1	4	16
O-L-G	0.528	25min	4	8
O-H-G	0.868	1 min	1	4
O-L-D	0.536	25min	4	8
O-H-D	0.832	1 min	1	4
Side-walk	1.26	< 1 min	25 min	2.5

DISCUSSION

Whole body vibration has been identified as a contributing factor to the "ride quality" of wheelchair mobility. Ride quality in this context generally refers to the comfort of the wheelchair user. The results of this pilot study demonstrate that a typical powered wheelchair exposes the user to discomfort after 2.5 hours for the "best" conditions and in less than one minute for the "worst" condition of riding over a sidewalk. It is conceivable that the whole body vibration a wheelchair user is exposed to may create a condition of fatigue-decreased proficiency after only one hour when outdoors. For the most severe conditions, an exposure limit of 2.5 hours is conceivable.

It is made clear in the ISO standard that it "is applicable only to situations involving people in normal health: this is, persons who are considered fit to carry out normal living routines." The fact that wheelchair users often have decreased trunk muscle function and other postural and stability insufficiencies implies the different limits established by the ISO standard may be higher than can be tolerated by typical wheelchair users. Further research is needed to better characterize the vibration response of wheelchairs and accessories, i.e. cushions. The new vibration data collection and analysis system described will make performing this research easier and more efficient.

ACKNOWLEDGMENTS

This work was funded by a grant from the National Institute of Disability and Rehabilitation Research, US Department of Education (H133E30014-95).

REFERENCES

1. Wheelchair III - Report of a Workshop on Specialty Adapted Wheelchairs and Sports Wheelchairs, VARRDS and RESNA, Sept. 1982

2. Wheelchair IV - Report of a Conference on the State-of-the-Art of Powered Wheelchair Mobility, NIDRR and University of Virginia RERC, RESNA Press, December, 1988

3. Bongers, P.M., Boshuizen, H.C., Hulshof, C.T.J, Koemeester, A.P. Back Disorders in Crane Operators Exposed to Whole-Body Vibration. Arch Occup Environ Health; 1988

4. Boshuizen, H.C., Bongers, P.M., Hulshof, C.T.J. Self-Reported Back Pain in Tractor Drivers Exposed to Whole-Body Vibration. Int Arch Occup Environ Health; 1990

5. Bovenzi, M., Zadini, A. Self Reported Low Back Symptoms in Urban Bus Drivers Exposed to Whole Body Vibration. Spine; V.17, No.9, 1992

6. Hulshof, C., Veldhuijzen van Zanten, B. Whole-Body Vibration and Low-Back-Pain, A Review of Epidemiological Studies. Int Arch Occup Environ Health; V59, 1987

7. Hansson, T., Holm, S. Clinical Implications of Vibration Induced Changes in the Lumbar Spine. Orthopedic Clinics of North America; V22, No. 2, 1991

8. Seidel, H., Bluethner, R., Hinz, B. Effects of Sinusoidal Whole-Body Vibration of the Lumbar Spine: The Stress-Strain Relationship. Int Arch Occup Environ Health; V57, 1986

9. ISO/TC 108. ISO 2631/1-1985(E) Evaluation of Human Exposure to Whole-Body Vibration-Part 1: General requirements.

Gerald Weisman
Vermont Rehab. Engineering Research Center
5 Arnold
University of Vermont
Burlington, VT 05405

TIRE ROLLING RESISTANCE, RIDE COMFORT & FLAME HAZARD

James J. Kauzlarich and John G. Thacker
University of Virginia
Charlottesville, VA

ABSTRACT

Two important competing design requirements for wheelchair tires are the rolling resistance and the ride comfort. The data show that there is a point at which increasing the softness of the ride dramatically increases the rolling resistance for solid tires. The UVA/MR maintenance free wheelchair tire strikes a compromise that gives a ride similar to that of a pneumatic tire.

Recent tests based on ASTM D3801-87 show that the UVA/MR tire which is a silica filled natural rubber exhibits a flame extinguishing time of less than 2 sec. Foamed polyurethane tires catch fire and continue to burn.

BACKGROUND

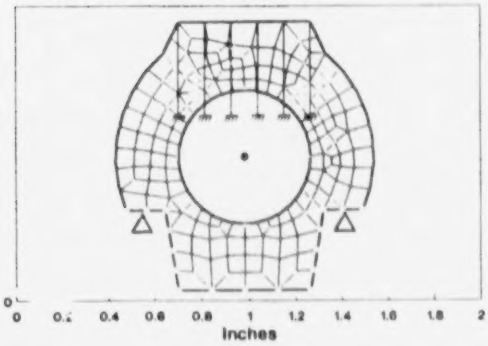
Everyone who has operated a car understands the importance of wheel alignment. In the case of wheelchairs it is equally important that the wheels are aligned in order to minimize tire wear and rolling drag. Since tires that are aligned perform pure rolling without sliding it may seem that there should be no rolling resistance under these circumstances. In recent years (1, 2, & 3) it has been shown that tires in pure rolling on smooth surfaces exhibit rolling resistance due to the hysteresis of the tire material. As the tire rolls and the rubber in contact with the ground deforms, it takes energy to compress the tire ahead of the contact point. Part of this energy is recovered as the tire expands to its original diameter behind the contact point. If hysteresis were zero all of the energy would be recovered and the tire would have no rolling drag, however all materials, and especially rubber materials, exhibit significant hysteresis under this cyclic loading and unloading of the tire contact. The unrecovered energy appears as heat generated in the tire, and causes the rolling resistance which must be overcome to propel the wheelchair. If in addition the wheels are not aligned the tires will perform a scrubbing action against the road which increases the rolling drag considerably. Of course there are other factors that affect the overall rolling drag of a wheelchair such as wind drag, bearing friction, accelerational forces, and friction with a rug or rough surface. We will only be concerned with tire hysteretical rolling resistance in this paper.

A very important wheelchair design factor is ride comfort. If the wheelchair were operated over a smooth surface the user would not experience any uncomfortable jolting and bumping. But real surfaces are not smooth, and it is necessary to protect the user as much as possible from the jolting accelerations due to surface bumps. Methods of protecting packages from damage during shipping use soft materials to absorb shocks, and most wheelchairs use the tire as a soft spring to minimize the shock acceleration experienced by the rider; only a few wheelchairs have built in spring suspensions to minimize shocks. It has been shown (4) that the acceleration transmitted to the package, the user in the case of wheelchairs, is proportional to the square root of the spring rate of the tires. When the tire spring rate is too high the users complain that the ride is uncomfortable. However, as the tire spring rate is reduced there is a point at which the rolling resistance increases dramatically. This characteristic is easily experienced when using pneumatic tires that have been allowed to go flat. Thus, we see that it is desirable to have a soft tire for ride comfort, but not too soft so that the rolling resistance is kept low.

All tires are a compromise in design, but one aspect of great importance that should not be compromised is fire hazard. There are no specific large scale tests to evaluate the performance of wheelchair tires in most real fire situations (5), but there are some laboratory tests such as ASTM D3801-87 (6) which do give a comparative result for fire risk. A discussion of the ASTM test applied to natural rubber and foamed polyurethane maintenance free wheelchair tires is presented.

TIRE ROLL, RIDE, & FIRE HAZARD

Fig 1 Maintenance Free Tire Profile Finite Element Model



UVA TIRE

The patented UVA/MR maintenance free wheelchair tire is a silica filled natural rubber tire with a cross section as shown in Figure 1. The spring rate of the tire is controlled by the size of the central hole for a given outer diameter. The tire is classified as a thick walled cylinder and is analyzed using finite element calculations. All of the test results reported are based on this tire with a few comparisons to other tires.

Figure 2 shows the radial loading and unloading of the tire versus displacement for tire contact with a smooth surface. As the tire is loaded, the work input is proportional to the areas under the loading curve of A+B. As the tire is unloaded, it does not follow the loading curve and the size of the area, A, represents the hysteresis of the tire material. As area A gets larger the hysteresis is larger, and the hysteresis factor which represents the loss in energy for the loading cycle is defined as the area A divided by the areas A+B. For Fig. 2 the hysteresis factor is measured as 0.15. Wheelchair pneumatic tires and polyurethane tires have hysteresis factors on the order of 0.10, with a corresponding lower rolling resistance. Racing bicycle tires (3) have a hysteresis factor on the order of 0.05 and a corresponding lower rolling resistance; but they are much more costly.

Fig. 2 Hysteresis & Spring Rate (Slope)

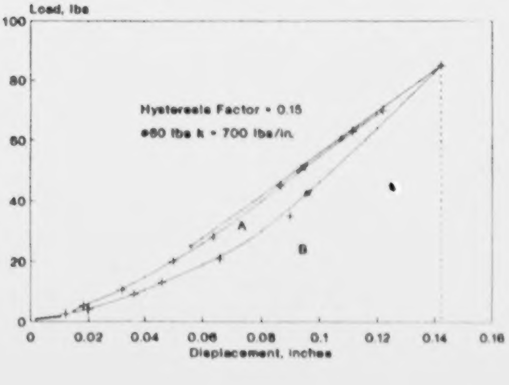
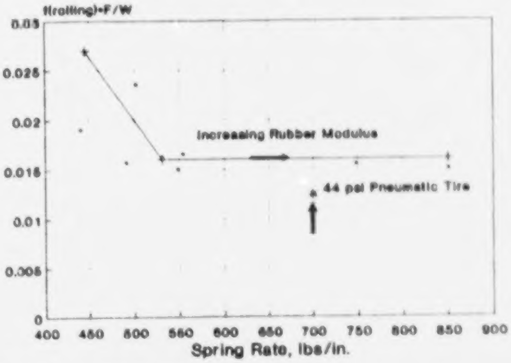


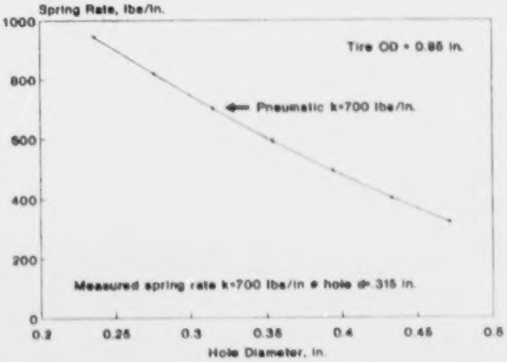
Fig. 3 Roll Resist Coeff vs Spring Rate



RIDE COMFORT

As discussed above the characteristic of the tire which is a measure of the ride comfort is the tire radial spring rate. A study of the spring rate and rolling resistance of the UVA/MR tire is shown in Fig. 3; where the rolling resistance coefficient, f(roll), is defined to be the force resisting rolling, F, divided by the weight on the tires, W. Here it is shown that as the tire becomes stiffer by increasing the rubber modulus, the rolling resistance coefficient, as well as F for fixed W, decreases to a point at which it remains constant. A data point for a pneumatic tire is also shown. As the spring rate is increased significantly beyond that for the pneumatic tire, users found the tire gave an uncomfortable ride. It is also possible to control the spring rate for a fixed rubber modulus by changing the hole diameter, and data shown in Fig. 4 gives the effect of hole size on spring rate. There is a

Fig 4 Effect of hole on spring rate



BEST COPY AVAILABLE

range of spring rates from about 550 lbs/in up to 750 lbs/in where ride comfort is good to acceptable without increasing rolling resistance. The UVA/MR tire was designed to have the same spring rate as the pneumatic tire, but this can be adjusted somewhat without increasing rolling resistance as shown in Fig. 3.

FIRE HAZARD

A comparative study of the fire hazard of solid wheelchair tires was based on ASTM D3801-87 (6). This test involved exposing the tire to two 10 second flame applications and determining the time for the flame to extinguish after the exposure. Two tires, the UVA/MR tire and a polyurethane foamed tire were tested with results listed in Table I below.

Table I

A. Bunsen Burner Applied for 10 sec.
  1. UVA/MR Natural Rubber Tire
  No ignition
  2. Polyurethane Foamed Tire
  Ignited, burnt vigorously, & dropped burning molten plastic.

B. Bunsen Burner Applied for 20 sec.
  1. UVA/MR Natural Rubber Tire
  Ignited, & flame extinguished within 1-2 seconds.
  2. Polyurethane Foamed Tire
  Ignited, burnt vigorously, & dropped burning molten plastic.

In addition, it is noted that the polyurethane tire emits cyanide fumes during combustion.

DISCUSSION

Our surveys of factors that inhibit wheelchair operation find that the pneumatic tire is the second most frequently mentioned problem; mainly because it goes flat. Maintenance free, airless tires, were found to give poor ride comfort. With the advent of maintenance free, "semi-pneumatic" tires, such as the UVA/MR tire (7) or foamed polyurethane tire, it has been found that these airless tires can give ride comfort comparable to that of pneumatic tires when properly designed. There is a small range of radial spring constant for the tire to give a comfortable ride, and the designer must take this into account while also considering rolling resistance. Too often, the maintenance free tire has a high spring rate and gives an uncomfortable ride. The experimental data presented gives the designer the tools to correct this problem.

In the area of fire hazard, a recent European Community directive requires that materials should be chosen which have the least risk of fire. In the case of tires, our study shows that the natural rubber tire is much superior in this regard to any of the polyurethane tires now on the market.

REFERENCES

1. Kauzlarich & Thacker, "Wheelchair tire rolling resistance and fatigue," J. of Rehab. R & D, July 1985, pp 25-41.
2. Moore, The Friction & Lubrication of Elastomers, Pergamon Press, 1972.
3. Kyle & Van Valkenburgh, "Rolling Resistance," Bicycling, May 1985, pp 140-152.
4. Gordon, Kauzlarich, & Thacker, "Tests of two new polyurethane foam wheelchair tires," J. of Rehab. R & D, Winter 1989, pp 33-46.
5. Brown, Physical Testing of Rubbers, App. Sci. Pub., London, 1979, p. 290.
6. ASTM D3801-87, "Standard Test Method for Measuring the Comparative Extinguishing Characteristics of Solid Plastics in a Vertical Position," ASTM Standards, October 1987, pp. 476-578.
7. Kauzlarich & Thacker, "The UVA/MR Maintenance - Free Wheelchair Tire," RESNA '94, June 17-22, 1994, pp. 327-329.

ACKNOWLEDGMENTS

Support for tire development and commercial application: "Sims-Tech," 2875 Queens Way, Thousand Oaks, CA 91362. (805)492-0989, FAX: (805)493-2833.
Dr. C. Metherell contributed fire hazard data.

AUTHOR ADDRESS

James J. Kauzlarich, University of Virginia, Mechanical Engineering Department, Charlottesville, VA 22903-2442. (804)924-6218, FAX: (804)982-2037. E-Mail: JJK@Virginia.EDU.

ADDING LOADS TO MANUALLY PROPELLED WHEELCHAIRS: COMPUTER MODELLING RESULTS OF THE EFFECT ON STATIC STABILITY

R. Lee Kirby, Donald A. MacLeod
Division of Physical Medicine and Rehabilitation, Dalhousie University and
Clinical Locomotor Function Laboratory, Nova Scotia Rehabilitation Centre
Halifax, Nova Scotia, Canada

ABSTRACT

In this study, we used a computer model to evaluate the relationship between the magnitude and position of added loads and the static rear and forward stability of occupied wheelchairs, beyond the range of loads that are practical to test empirically. We added loads from 0-100 kg (in 10-kg increments) to each of five positions. The greatest effect on rear stability was with the load in the footrest position, where 100-kg loads increased rear stability by about 300% and where a 70-kg load was sufficient to tip the occupied wheelchair over forward. Only loads in the the high-rear position reduced rear stability, but only to a maximum of about 30% of the unloaded values. These findings are relevant to designers, clinicians and wheelchair users.

BACKGROUND

Because most wheelchair users must have their hands free to propell the chair, knapsacks or other carriers are important for carrying the personal effects that others might carry in a purse or briefcase. In addition, some wheelchairs are modified by the addition of items to assist propulsion, communication, function or posture. From three earlier studies on the effect of added loads on rear and forward stability (1-3), it is known that the magnitude and position of the added load can affect the static rear and forward stability of occupied wheelchairs, but the magnitude of the added loads was in the 1-10 kg range.

OBJECTIVE

The object of this study was to use a computer model to evaluate the relationship between added loads and stability, beyond the range of loads that are practical to test empirically.

METHODS

We used a computer model that we have developed for the evaluation of static wheelchair stability. The 3D position of the body segments were digitized from photographs of a living subject (female, 54 kg, 166 cm) sitting in a wheelchair with the arms on the armrests. The wheelchair user was modelled as 14 segments, with the mass and position of each segment's center of mass (CG) from Dempster's data (4). The rear-wheel-drive manually propelled wheelchair (an E & J Traveller) (19 kg) was modelled as five components -- the frame and the four wheels. The location of the CG of each wheel was assumed to be at the wheel's center; the frame's CG position was determined using a balance board.

Loads from 0-100 kg (in 10-kg increments) were modelled in five positions (Figure 1). The positions (and their x,y coordinates, in cm from the origin at the right rear axle) were: high rear (HR) (-1, 42); low rear (LR) (8, -13), beneath the seat and behind the crossbrace; on the lap (LAP) (27, 31); low anterior (LA) (30, -13), beneath the seat anterior to the crossbrace; and on the footrests (FR) (70, -14).

With a set of coordinates defined for each body and chair segment relative to the origin, calculating a system CG and subsequent tipping angles is a matter of applying equations of static physics. Note that the overall wheelchair CG location is appropriate only for the estimation of rear stability (RS) with the rear wheels locked (RS_L), where the axis of rotation is assumed to be at the contact point between the rear wheel and the ground. For RS with the brakes unlocked (RS_{UL}), the weight of the rear wheels is discounted and the axis of rotation is assumed to be at the rear-wheel axle. For forward stability (FS), because the casters are unbraked, the weight of the casters is excluded and the axis of rotation is assumed to be at the caster axles.

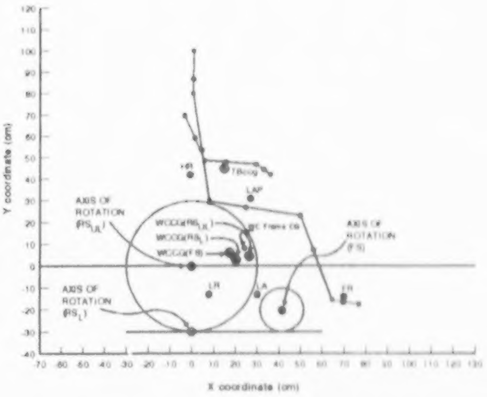


Figure 1. Stick figure of occupied wheelchair. The segment endpoints and CGs are shown. The targets indicate the CGs of the wheelchair occupant's total body (TBCOG), and the CGs of the wheelchair appropriate to stability determinations in the RS_{UL}, RS_L and FS directions. The axes of rotation and the positions of the added loads are also shown.

RESULTS

The results are shown in Figure 2. The greatest effect on RS was with the load in the FR position, where 100-kg loads increased RS by about 300% and where a 70-kg load was sufficient to tip the occupied wheelchair over forward. Only the HR position reduced RS, but only to a maximum of about 30% of the unloaded stability values.

DISCUSSION

These results are consistent in direction and relative magnitude to those of the earlier studies conducted in the 0-10 kg range (1-3). Although the single subject and wheelchair modelled limit the generalizability of our findings, there are clear implications regarding the optimum position in which to add load. If one wishes to raise RS, the FR position would be the first choice of location; to lower RS, the HR position would be used. To raise FS, the LR position would be preferred, whereas to lower FS, the FR position would be used. To minimize the effect of added loads on stability, the LAP position would be preferred.

However, the choice of a wheelchair position in which to add loads reflects more considerations than simply stability. For instance, both of the positions beneath the seat would be difficult to reach for some wheelchair users. Furthermore, the relative weight on the front and back wheels affects rolling resistance and downhill-turning tendency, among other parameters.

We conclude that the position and magnitude of added loads has a clinically significant effect on the static stability of occupied wheelchairs. These findings are relevant to designers, clinicians and wheelchair users.

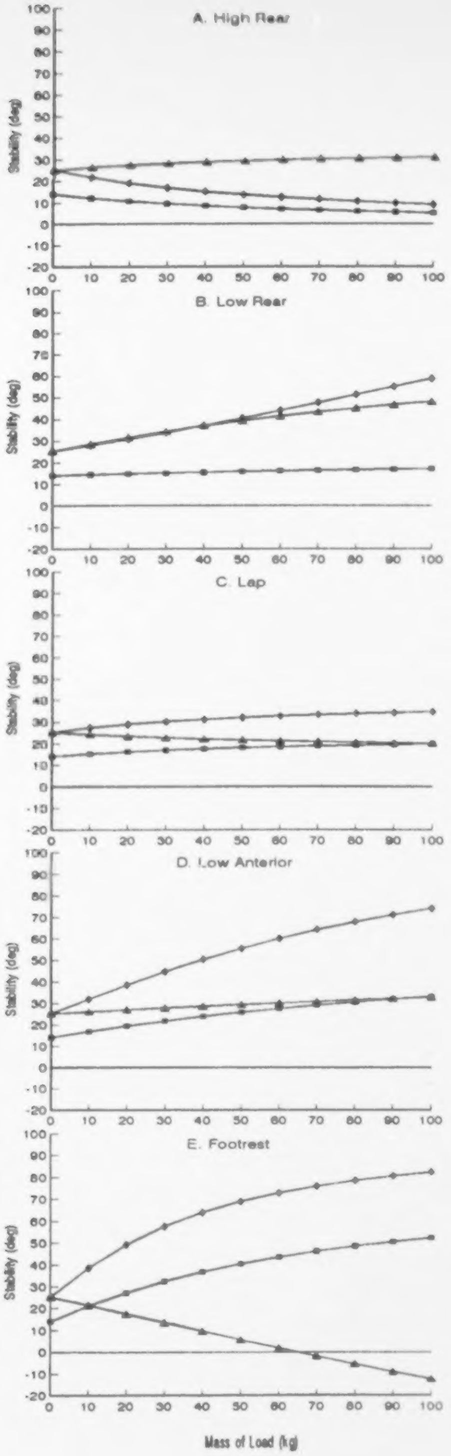


Figure 2. Effects on stability of adding loads from 0-100 kg to each of the positions. The diamonds, squares and triangles represent the RS_{UL}, RS_L and FS values respectively.

REFERENCES

1. Loane TD, Kirby RL: Low anterior counterweights to improve static rear stability of occupied wheelchairs. Arch Phys Med Rehabil **67**: 263-266, 1986.

2. Kirby RL, Ashton BD, Ackroyd-Stolarz SA. Static rear and forward stability of occupied wheelchairs: effect of the magnitude and position of added loads. Arch Phys Med Rehabil 73: 1014, 1992.

3. Kirby RL, Ashton BD, Ackroyd-Stolarz SA. Effect of position and load of a knapsack on the static and dynamic forward and backward stability of an occupied wheelchair. Clin Invest Med 15 (Suppl): A129, 1992.

4. Demspter WT. Space requirements of the seated operator (WADC-TR-55-159). Wright-Patterson A.F.B., Ohio: Aerospace Medical Research Laboratory.

ACKNOWLEDGEMENTS

We thank the Medical Research Council of Canada for funding.

Dr. R.L. Kirby
Dalhousie University
1341 Summer Street
Halifax, N.S.
Canada, B3H 4K4
Phone: (902) 492-6178
Fax: (902) 425-6466
E'mail: KIRBY@AC.DAL.CA

EXPERIMENTAL LOCATION OF THE AXIS OF ROTATION FOR REAR STABILITY OF WHEELCHAIRS WITH AND WITHOUT CAMBER

Guy Trudel MD[1], R. Lee Kirby MD[2], Adam C. Bell ScD PEng[3].
[1] Research Fellow, [2] Professor, Division of Physical Medicine and Rehabilitation,
Department of Medicine, Dalhousie University, [3] Professor and Dean, Faculty of Engineering,
Technical University of Nova Scotia, Halifax, Nova Scotia, Canada.

ABSTRACT

The location of the axis of rotation is one of two items of data necessary to model the stability of occupied wheelchairs (the other being the location of the center of mass). To our knowledge, the experimental assessment of this value has never been reported. We calculated the location of the axis of rotation for rear stability of occupied wheelchairs with the brakes locked and unlocked. We also assessed the effect of camber of the rear wheels on the axis of rotation with the brakes unlocked. We used a photographic study and the instantaneous-center-of-rotation technique. We found that the functional axis of rotation was slightly higher than would have been expected theoretically. Negative rear-wheel camber brought the axis of rotation forward compared with no camber. Within the precision and validity of the technique used, we feel these results are of value for the modelling of wheelchair stability. They also allow better comprehension of the effect of camber on wheelchair stability.

BACKGROUND

Wheelchair accidents due to instability are a concerning problem (1,2). Negative camber of the rear wheels (angling the bottoms of these wheels outwards) was shown to be a risk factor for accidents, and to increase the proportion of accidents in the rear direction (3). On experimental testing, negative camber decreased rear stability with the brakes locked and unlocked. For modelling purposes, the stability of wheelchairs can be determined by locating the composite center of mass of the wheelchair and occupant and the axis of rotation around which this center of mass is rotating. The axis of rotation was assumed to be at the point of contact between the wheel and the ground for the brakes-locked situation, and at the rear-wheel axle level when the brakes were unlocked (4). To our knowledge, an experimental demonstration had not been reported in the literature. We tested occupied wheelchairs with the brakes locked and unlocked to find out where the axes of rotation were located. We also suspected that camber of the rear wheels would change the location of that axis of rotation.

RESEARCH QUESTION

We hypothesized that i) the axis of rotation for rear stability of an occupied wheelchair with the brakes locked would be behind the rear-wheel axle and at the level of the ground, ii) that it would be coincident with the rear-wheel axle with the brakes unlocked and iii) that camber would affect the axis of rotation with the brakes unlocked.

METHOD

We selected 3 different manually-propelled, rear-wheel-drive wheelchairs, two with straight wheels and one with cambered rear wheels (19.1° of negative camber). The diameter of the rear wheels was 61 cm (including tires). The wheelchairs were occupied by a 95th percentile anthropomorphic test dummy (Hybrid II). Three markers were put on the wheelchair frame. We tipped the wheelchair backwards from 0° to 16° of tip by pulling the front part of the frame. We took lateral photographs in controlled conditions at intervals of 1 degree. Then, we projected the slides made from these experiments and superimposed the markers' locations on paper.

We used the instantaneous-center-of-rotation technique to locate the axes of rotation. This technique consists of joining with a chord the same point of an object at two consecutive times. This chord is then bisected and a perpendicular dropped. When the procedure is repeated with other points, the intersection of the perpendicular lines define the axis of rotation (Fig. 1). A centrode and a functional axis of rotation (an axis of rotation that describe the movement from the zero position to the angle of instability) were obtained for each experiment.

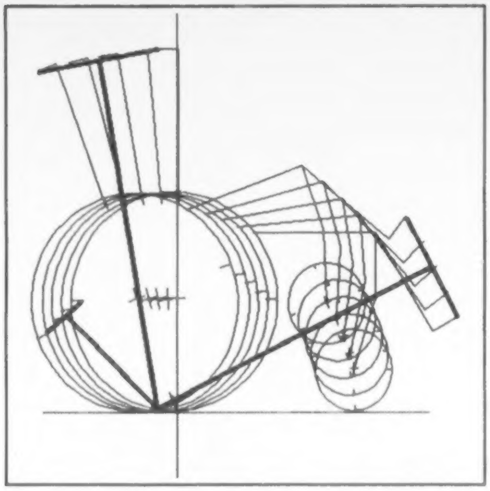


Figure 1. Illustration of the instantaneous-center-of-rotation technique used to locate the functional axis of rotation for rear stability (brakes locked) of an occupied wheelchair.

RESULTS

With this method, the axis of rotation for rear stability with the brakes locked was found to be approximately 3 cm behind the rear-wheel axle for a wheelchair tipped from 0° to 16°. It was also found to be 1 cm above the level of the ground (Fig. 2).

With the brakes unlocked, the axis of rotation was found to be approximately 1 cm behind and 1 cm above the rear-wheel axle. Negative camber moved the axis of rotation in the forward direction, positioning it approximately 2 cm above and 1.5 cm in front of the rear-wheel axle (Fig.3).

DISCUSSION

This study aimed at locating the axis of rotation of occupied wheelchairs during tipping in the rear direction. This value is important for the modelling of wheelchair stability. We used the instantaneous-center-of-rotation technique and found that the axis of rotation was behind the projection of the rear-wheel axle on the ground. This is in agreement with the theoretical situation of a rolling wheel where it should be located at a distance of [Pi x D x stability angle/ (360°x 2)] behind the projection of the rear-wheel-axle on the ground, where D is the diameter of the wheel (including tires).

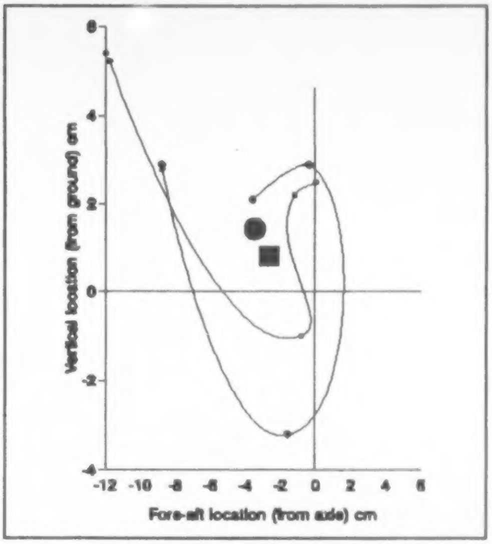


Fig. 2 Experimental results for locating the axis of rotation for rear stability (brakes locked) of occupied wheelchairs. Small circles: instantaneous centers of rotation found at 0°-4°, 4°-8°, 8°-12°, 12°-16° of backward tip; large circle: functional center of rotation; arrowed lines: centrodes; small and large squares: same as circles, but with wheelchair 2. Positive values on the X axis are in front of the rear-wheel-axle.

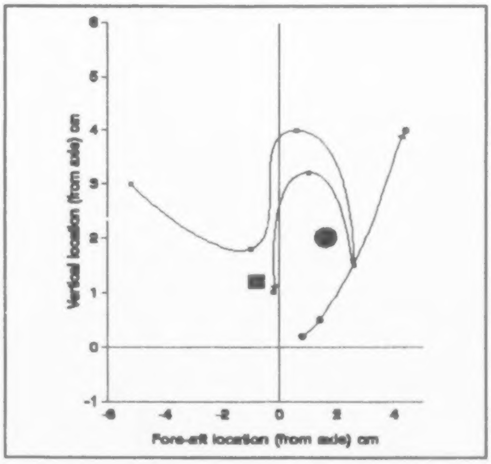


Fig. 3 Location of the axis of rotation for rear stability (brakes unlocked) with camber (circles) and without camber of the rear wheels (squares). Otherwise, legend as defined in Fig. 2.

BEST COPY AVAILABLE

This formula simply describes half the arc of the wheel between the point of contact of the wheel with the ground at 0° and the new point of contact at the angle of stability.
But we also found that the functional axis of rotation was above the level of the ground. This is in contradiction with the theory for axes of rotation between rolling rigid bodies that locate the axis of rotation at the point of contact between these two bodies (5). This can be partly explained by the deformability of the objects that have distorted the markers' location.

Deformability of the dummy, of the wheelchair frame, of the back canes backwards, of the flexible backrest and seat slings and of the tires are likely to have happened. An analysis of the effects of those forces suggests a resulting axis of rotation that would be higher and in front of the actual value. Another reason is the technique used; it assumes that no sliding took place between the two bodies. This is limited in this situation by the pulling forces applied to the front part of the frame to tip the wheelchair and by the creeping of the pneumatic tire in a rolling motion. Finally, the patch area of contact between the two bodies (instead of a single point of contact) might have led to uncertainty of measurements.

For the brakes-unlocked situation, the axis of rotation was not found to be exactly at the rear-wheel axle. The same factors as with the brakes locked situations apply, namely deformability of the two objects (leading to relative movement between the markers), limitations of the technique and precision of the measurements.

With camber, a definite difference was observed. The axis of rotation was located in front of and above the rear-wheel axle. We believe this is due to the toe-out angle that cambered wheelchairs acquire when the wheelchair is tipped backwards with the brakes unlocked. Also, the wheels become vertically straighter as the cambered wheel is tipped backwards, raising the axis of rotation.

These results will help refine models aimed at estimating the rear stability of occupied wheelchairs. The last finding on the effect of camber provides deeper insight on why a wheelchair' stability changes with a change in camber. We hope that this study will lead to better awareness and stimulate research in the field of safety in wheelchairs and specifically the impact of changing camber.

REFERENCES

1. Kirby RL, Ackroyd-Stolarz SA, Brown MG, Kirkland SA, MacLeod DA. Wheelchair-related accidents due to tips and falls among noninstitutionalized users of manually propelled wheelchairs in Nova Scotia. Am J Phys Med Rehabil 73:319-330, 1994.

2. Kirby RL, Ackroyd-Stolarz SA. Wheelchair safety: adverse reports to the United States Food and Drug Administration. Arch Phys Med Rehabil 75: 1032, 1994. (Abstract)

3. Trudel G, Kirby RL. Effects of camber on wheelchair stability. Proceedings of the RESNA '94 Annual Conference. 315-7, 1994.

4. International Organization for Standardization. Determination of static stability. Draft revision, Issue 9, November 24, 1994.

5. Faires VM. Kinematics McGraw-Hill Book Company, 114-160, 1959.

Funded by the Medical Research Council of Canada and the Rick Hansen Man-in-Motion Foundation/Canadian Paraplegic Association/Alberta Paraplegic Association.

Acknowledgements. We thank D.A. MacLeod for his assistance.

Guy Trudel MD[1]
Research Fellow
Division of Physical Medicine and Rehabilitation,
Dalhousie University
1341 Summer Street, Halifax, Nova Scotia
Canada. B3H 4K4
Phone: (902) 492-6218
Fax: (902) 425-6466

STATIC STABILITY TESTING OF STAND-UP WHEELCHAIRS

RA Cooper[1,2], H McGee[2], M Apreleva[1,2], SJ Albright[1,2], DP VanSickle[1,2], E Wong[2], ML Boninger[1,2]
Rehabilitation Science and Technology and Bioengineering
School of Health and Rehabilitation Sciences
University of Pittsburgh, Pittsburgh, PA 15261

Human Engineering Research Laboratories
Veterans Affairs Medical Center
7180 Highland Drive, Pittsburgh, PA 15206

Abstract

Static stability testing measures the angle at which the wheelchair with a dummy will tilt in each of three directions: rearward, forward and laterally. The static stability of four stand-up wheelchairs were investigated. Each wheelchair was tested in the seated and standing positions. The results for rearward static stability for the stand-up wheelchairs (mean 11.3 ± 7.57) while seated are not significantly different ($p > 0.05$) than those reported for standard wheelchairs (mean 7.3 ± 2.59). Our experience suggests that knee, hip and chest restraints are required to conduct the tests safely and repeatably in the standing position. Some wheelchairs had difficulty lifting the 100 kilogram dummy.

Introduction

There are four basic types of stand-up wheelchair: manual drive with manual lifting mechanisms, manual drive with power lifting mechanisms, electrically powered drive with powered lifting mechanisms, and fixed standing position (3). The first three types of stand-up wheelchair change configuration from sitting to standing and vice-versa. During this transition process a significant portion of the rider's body weight must be supported by the lifting mechanism. The seat of the wheelchair which supports the rider is often rotated about an axis parallel to the user's knees, causing the user to assume a standing position (the users knees are secured via a padded support). All wheelchairs must be tested for their static stability. When negotiating a ramp or traversing a door threshold, the wheelchair tilts. A wheelchair may tilt while rolling over uneven terrain or when crossing common obstacles. Static stability testing measures the angle at which the wheelchair with a dummy will tilt in each of three directions: rearward, forward and laterally. These angles give the user, manufacturer, and prescriber a measure of stability in a variety of static situations. We investigated the static stability of four stand-up wheelchairs.

Research Question International Standards Organization (ISO) and American National Standards Institute Standards (ANSI) for stand-up wheelchairs are under development (3, 4). Static stability testing represents an important component of the standards development process. The purpose of this investigation was to develop a standard for performing static stability testing, and to collect data from several wheelchairs.

Methods

The static tip angles of four stand-up wheelchairs (**Table 1**) were measured in three directions (rearward, forward, and lateral). In each case, the chair was loaded with a 100-kg ISO dummy (2, 5). Each wheelchair was tested in the seated and standing positions. Each test was performed on an inclined ramp with the appropriate surface coefficient of friction and the wheelchair wheel locks activated. If sliding or rolling occurred, straps were added and the test was repeated (1,3,6). The straps were attached to the edge of the platform, wrapped around the wheels or casters, and then the other end was attached to the frame of the chair (the location depending on the direction being tested). If the straps were used, the brakes were deactivated. Each test was performed with the casters in the least advantageous position.

Table 1. Manufacturer and Model Wheelchair Tested

Manual	Power
Levo Compact LC	Permobil Chairman
ReGain Beta	Levo Mobile LCM
Prototype	

Note: manual: manually driven in seated position. power: electrically driven in seated position.

During rearward stability testing, the straps were hooked onto the platform, run under the rear wheels (casters) and attached to the back of the chair . Removing a standard piece of paper from under the wheels about to lift-off with a 10 gram force determined whether or not the chair had tipped. With a protractor, the angle of tip was measured to an accuracy of 0.5 degrees. During forward stability testing, the straps were hooked onto the platform, run under the front casters (wheels) and attached to the side of the wheelchair frame. In the transverse direction, the straps were hooked onto the platform, run under the front and rear wheels of the downhill side and attached to the side of the chair.

Each test was performed in the sitting and standing position. The order in which the chairs were tested was chosen randomly, as was the order of the direction in which each chair was tested. All tests were done for the same wheelchair before transferring the dummy to another wheelchair.

Results

The angles of tip in each direction for chairs in the seated position are shown in **Table 2**. Each chair varied in its performance. Those angles recorded as 20+ signify that the chair went to 20 degrees without tipping and the test was terminated at that point. Straps were required in nearly every case. The results for rearward static stability for the stand-up wheelchairs (mean 11.3±7.57) while seated are not significantly different ($p > 0.05$) than those reported for standard wheelchairs (mean 7.3±2.59) (1).

The data for the tests conducted in the standing position are given in **Table 3**. Tests for Chair 2 were done without straps. However, Chair 1 rolled in its first set of tests. Straps were added while testing Chair 1 as described earlier. The angles are similar in all cases except the downhill direction. The brakes on Chair 1 could not hold on an inclined surface with 3 degree angle. For this reason, none of the tests were attempted without straps.

Table 2. Static stability angle with loaded wheelchair in the seated position.

Direction	Chair Number	Angle (degrees)	Event	Strap Angle
	Chair 1	3	Roll	8
Facing uphill	Chair 2	6	Tip	N/A
	Chair 3	16	Roll	20+
	Chair 1	3	Roll	20+
Facing downhill	Chair 2	10	Roll	18.5
	Chair 3	13.5	Roll	20+
	Chair 1	3	Roll	21
Facing transversely	Chair 2	unavailable	Roll	17.5
	Chair 3	unavailable	Roll	16

In the seated position, the Chair 3 began to roll when faced transversely. We were unable to safely record the angle accurately. There is no standing data for Chair 3 because, when loaded with the dummy, this chair could not stand fully. Several attempts were made to use the dummy with this wheelchair. The strap connecting the leg support to the chair which was provided by the manufacturer broke. A more substantial strap was added to replace the OEM component, and it was also broken during an attempt to make the chair stand. To investigate the situation further, an individual weighing 79.5kg attempted to stand in Chair 3. The leg supports could not withstand the force exerted by this individual. In a final attempt with the dummy, the leg support was chained to the chair. As the dummy was brought to a standing position the leg support bent. At this time the test was terminated.

Chair 4 was randomly selected to be tested in the standing position prior to the sitting position. The dummy was positioned in the stand-up wheelchair as per the manufacturer's specifications. The controls were activated to stand the dummy up in the wheelchair. Approximately midway during the lifting process, the lifting actuator began to grind, and then slip. The mechanism was unable to lift the dummy. The dummy was lowered back to the seated position with assistance from the test technicians. The lifting mechanism was destroyed and returned to the manufacturer for repair/redesign. No further testing was conducted with this stand-up wheelchair.

Discussion

Stand-up wheelchairs can be tested using the draft stand-up wheelchair standard as proposed. Our experience suggests that knee, hip and chest restraints are required to conduct the tests safely and repeatably in the standing position. Although, stand-up type wheelchairs have only recently gained popularity it appears that they do not suffer from problems with static stability, if used properly. All of the manufacturers recommended that their product not be used on any slope while in the upright position. However, they appear to have accounted for the change in inclination seen when crossing a door threshold. The static stability results of these wheelchair while in the seated position are within normal ranges for most common manual and power wheelchairs.

The difficulties we had with the lifting mechanisms of the wheelchairs were disturbing. Chairs 1, 3 and 4 had exhibited problems with their lifting mechanisms when elevating a 100 kilogram dummy. The manufacturer of Chair 1 made modifications in time for us to retest the wheelchair. The lifting mechanisms do not appear to be robust enough in their design or the range of adjustment of the knee support and knee joint can not accommodate large, heavy individuals. These results obviate the need for greater testing, and test development.

Table 3. Static stability angle with loaded wheelchair in the standing position.

Direction	Chair Number	Angle (degrees)	Event	Strap Angle
Facing uphill	Chair 1	10	Roll	12
	Chair 2	16	Tip	N/A
	Chair 3	N/A		N/A
Facing downhill	Chair 1	6	Roll	20+
	Chair 2	12.5	Tip	N/A
	Chair 3	N/A		N/A
Facing transversely	Chair 1	12.5	Roll	16
	Chair 2	13	Tip	N/A
	Chair 3	N/A		N/A

REFERENCES

1. Cooper RA, Stewart KJ, and VanSickle DP, Evaluation of Methods for Determining Rearward Static Stability of Manual Wheelchairs, Journal of Rehabilitation Research and Development, Vol. 31, No. 2, pp. 144-147, 1994

2. Cooper RA, Myren C, Ster JF, VanSickle DP, Stewart KJ, Reifman G, and Heil TA, Design of an Anthropomorphic ISO-RESNA/ANSI Wheelchair Test Dummy, Proceedings 16th Annual RESNA Conference, Las Vegas, NV, pp. 283-285, 1993.

3. ISO Working Group 9, Stand-up Wheelchair Draft Standard, WG 09-01, April, 1994.

4. RESNA Standard: *Wheelchairs - Static Stability,* RESNA WC/1, RESNA Press, Washington, D.C., 1990

5. RESNA Standard: *Wheelchairs - Test Dummies*, RESNA WC/11, RESNA Press, Washington, D.C., 1989

6. Ziegler JW. *Instructions for New ISO 7176/1 Static Stability Test*, Forschungsinstitut fuer Orthopaedietechnik, June, 1992.

Acknowledgment

This work was partially supported by a contract from the US Food and Drug Administration, and the Rehabilitation Engineering and Research Center on Technology to Improve Wheeled Mobility, Nation Institute on Disability and Rehabilitation Research, HE133005.

Rory A. Cooper, Ph.D.
Human Engineering Research Laboratories
University of Pittsburgh
Veterans Affairs Medical Center
7180 Highland Drive
Pittsburgh, PA 15206
TEL: 412-365-4850
FAX: 412-365-4858

SMARTWHEEL: DEVELOPMENT OF A DIGITAL FORCE AND MOMENT SENSING PUSHRIM

David P VanSickle, Rory A Cooper, Rick N Robertson
Department of Rehabilitation Science and Technology
School of Health and Rehabilitation Sciences
University of Pittsburgh
Human Engineering Research Laboratories
Research Services, Highland Drive VAMC
Division of Physical Medicine and Rehabilitation, UPMC

Abstract

A new digital version of the SmartWheel has been developed to improve the quality of the kinetic data by reducing electrical noise from external sources. Also, the new digital version eliminates the need for a PC mounted A/D converter card making the SmartWheel more flexible by allowing the use of a laptop computer. The new design is based on an MC68HC11A1 microcontroller located on the SmartWheel. The analog data is sampled and converted to digital form by the microcontroller and then transmitted to the RS-232 serial port of a PC. The angular position is determined from an optical encoder using a quadrature algorithm implemented in software on the microcontroller. The percent linearity is 99.1 % for a moment applied in the plane of the wheel. The externally introduced noise has successfully been minimized with the limiting factor of the systems resolution being the microcontroller's A/D resolution.

Introduction

The SmartWheel (**Figure 1**) is part of a complete analysis system used to investigate the biomechanics of an individual pushing a wheelchair [1,2,3,4]. Other components of this system include a video digitizing system, and a wheelchair dynamometer. The SmartWheel consists of a plastic composite wheel with three beams rigidly attached to the hub. Linear bearings slide over the ends of the beams and the linear bearing housings are attached to the pushrim. Each beam is instrumented with two sets of strain gages sensitive to perpendicular directions of bending. An optical rotary encoder is attached to the frame of the wheelchair and is turned by the SmartWheel. The force acting on the push-rim and the moment generated about the hub are correlated with the signals from the six strain gages.

Problem Statement

The problem being addressed with the new digital design is the elimination of electrical noise produced when the analog signals are transmitted from the SmartWheel to an analog to digital (A/D) converter card inside a PC. There are two main sources of this electrical noise. First, the inside of a PC case is an electrically noisy environment and does not make a good location for sensitive A/D converters. Second, the analog signals must be transmitted from the SmartWheel through a slip-ring and over a distance of up to 40 ft. An additional motivation for the digital design is the elimination of the PC mounted A/D converter card so that a laptop computer can simply be used with the SmartWheel.

Filtering algorithms have been developed [5] which can improve the data by removing noise, but this is always accompanied by some signal loss. The best solution is to minimize the noise. The new digital SmartWheel design places a microcontroller based analog to digital (A/D) converter on the SmartWheel. The converted values are transmitted from the SmartWheel to an IBM compatible personal computer (PC) in digital form using an RS-232 serial port. On **Figure 1**, the location of the six amplification circuit boards are labeled as circuit boards "1" through "6". The new microcontroller circuit board is labeled with "A/D".

Method

Design

The microcontroller used is Motorola's MC68HC11A1. The MC68HC11A1 microcontroller contains an internal, 8-bit, A/D converter, and an eight channel analog multiplexer. These microcontrollers also contain a serial port and a small amount (512 Bytes) of electronically

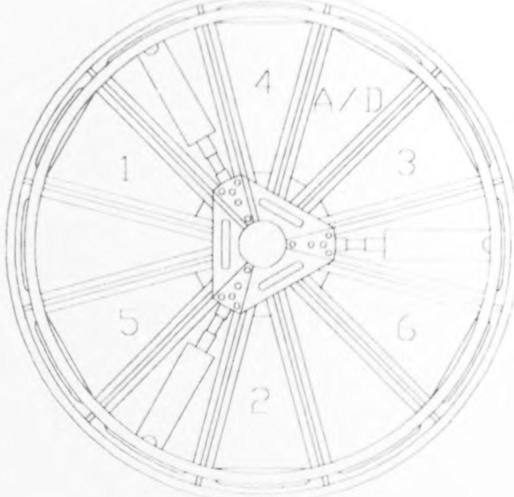


Figure 1 Digital SmartWheel

erasable memory (EEPROM). Another advantage of the MC68HC11 series is that it can operate in a single chip mode which requires a minimum of external components. The SmartWheel must be reliable while being operated in a clinical environment. Also, the mass of the SmartWheel must also be kept within the range of a normal wheelchair wheel so that the individual pushing the wheelchair does not use an altered or otherwise unnatural stroke. The self contained nature of the MC68HC11A1 allows for reliable circuitry with a minimal mass.

The SmartWheel angle of rotation with respect to the wheelchair frame is measured with an optical rotary encoder (HP QEDS-8850). The encoder puts out two pulses which are 90° apart from each other. One of the pulses trains (output A) from the encoder triggers an interrupt driven software routine running on the microcontroller whenever an upward or downward edge of a pulse is detected. This software routine checks whether the trigger was an upward or a downward edge, and then checks the logic level of the other signal (output B) from the encoder. There are four possible combinations. Two combinations indicate the wheel is rotating in the forward direction, and two indicate the wheel is rotating in the backward direction. A software counter is indexed appropriately by the interrupt routine. This technique is called half-quadrature. With the 300 pulse per revolution optical encoder, this technique results in 600 pulse per revolution (0.6°) position accuracy. The maximum usable speed of the SmartWheel has been estimated to be 30 mph. At this speed, the pulse rate would be fast enough such that the interrupt routine would consume 25 % of the processors time.

The microcontroller software samples the A/D channels at 240 Hz. This sampling rate was chosen purposely to be a multiple of the 60 Hz sampling frequency used by most video systems. After each sample, the data is sent from the microcontroller to the PC in packets. At the beginning of the packet is a break character. After the break character, the digitized voltages are sent, followed by two bytes for the angular position of the wheel. Finally an index value is sent. The index value is a simple 8-bit counter which increments after every packet is transmitted. The index is used to indicate if a packet is lost in transmission. If a transmission error occurs, the break character of the next packet will realign the receiving order for the PC software and a gap in the index count will indicate a missing or bad packet. The bad or missing packet can be removed from the data by averaging the information from the packet just before and just after the problem occurred. Other filtering methods could also be used. Due to the large amount of data sent over the serial port, the baud rate for communication is set at a relatively high 38,400 bits/sec. To achieve this rate, interrupt driven software routines had to be developed for the PC so that data in the serial port buffer would be fetched and stored before being overwritten by new data.

A six channel mercury slip-ring was used on the previous version of the SmartWheel to transmit the analog signals off of the wheel. A three channel mechanical slip-ring was used to power the wheel. In the new digital design, the six channel mercury slip-ring was retained and the mechanical slip-ring eliminated. In the new design, three of the channels are used for +/- 15 Volts, and ground. Two of the other channels are used to transmit pulses onto the wheel from the optical encoder. The sixth channel is used to transmit the data as it is collected from the SmartWheel to a PC using an RS-232 serial port. An interface board attached to the wheelchair frame is used to interface the signals from the slip-ring, the power supply, and the RS-232 port of the PC. The interface board also contains circuitry to power the encoder.

Design Analysis

The digital SmartWheel is calibrated in a manner similar to previous versions of the SmartWheel [6]. Equations have been derived relating the output of the six strain gages to a three dimensional force vector and a three dimensional moment vector [6]. Weights are applied in various configurations to the SmartWheel to induce known forces and moments. The coefficients of these equations are then determined by linear regression. The purpose of this section is to focus on the microcontroller A/D circuit board. One configuration is used and the percent linearity, maximum range, and minimum resolution are determined.

The SmartWheel was mounted on a test stand with the axle horizontal. Seven different weights were hung downward from one beam with that beam horizontal. Equations (1) and (2) were used to determine the moment about the hub (M_z) and vertical force produced by this weight (F_y). The digital outputs from each set of strain gages are Channels 1 - 6.

$$M_z = C_1(\mathrm{Ch4} + \mathrm{Ch5} + \mathrm{Ch6}) \tag{1}$$

$$F_y = C_2\begin{pmatrix} \mathrm{Ch4}\cos(\theta) + \mathrm{Ch5}\cos(\theta + 120) \\ + \mathrm{Ch6}\cos(\theta + 240) \end{pmatrix} \tag{2}$$

The coefficients C_1 and C_2 where determined by regression and the maximum deviation from this regression line used to calculate the percent linearity.

Results

The maximum deviation from the regression line was 0.703 N-m from the moment measurement and 7.69 N for the force measurement. Both of these values represent less than a one bit error. Therefore, the limiting factor of these measurements is the resolution of the A/D converter. The percent linearity is 99.1 % for the moment measurement and 98.9 % for the vertical force measurement. Based on the value of the coefficients C_1 in Equation (1), the maximum measurable moment about the hub (M_z) is 76.8 N-m, and the maximum measurable force in the plane of the wheel (F_x, and F_y) is 154 N. The maximum measurable moment and force out of the plane of the wheel (M_x, M_y, and F_z) are designed to be 3.39 times smaller.

Figure 2 illustrates the digitized output from the three SmartWheel beams while the wheel is being rotated. This output pattern was first observed during the initial testing of the digital SmartWheel circuitry, and was originally assumed to be noise. Closer inspection reveals three sinusoidal waves shifted by from one another by 120°. This data is from the beam strain gages which are sensitive to loading in the plane of the wheel. The weight of the pushrim and mounting hardware applies a downward force due to gravity. As the SmartWheel turns, it rotates relative to this force producing the sinusoidal patterns.

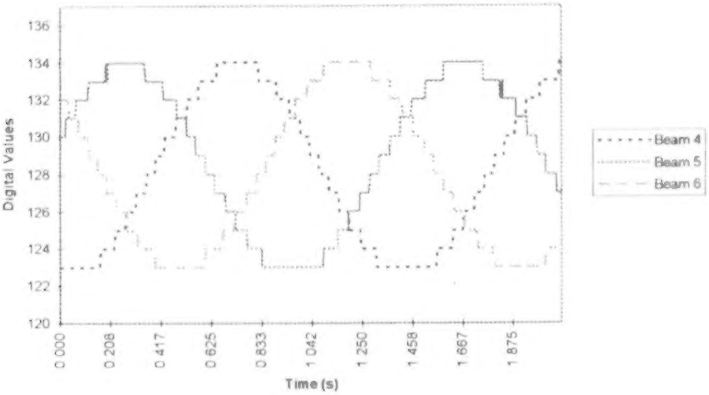


Figure 2: Sinusoidal variations in digital output due to the weight of the pushrim during wheel rotation. Peak-to-peak is 11 digitization units or 2.9 N.

Discussion

Given results such as shown in **Figure 2**, this new digital SmartWheel should be able to distinguish subtleties in the stroke kinematics not previously detectable. The new digital SmartWheel has already proven to be more reliable than previous versions when it was used during the Wheelchair Sports USA (WSUSA) / United States Olympic Committee (USOC)'s Paralympic Training Camp held at Sacramento, CA.

Future designs are planned. The first such change is to use a different version of the microcontroller (MC68HC711G5) which has a 10-bit A/D converter and a larger programming space (2 Kbytes). The move to a 10-bit A/D is motivated by the desire to increase the range of the measurable forces and moments of the SmartWheel. This should make the SmartWheel usable for a wider variety of circumstances. Another design variation is the addition of memory to the microcontroller circuit and conversion of the SmartWheel to battery power. This would allow data to be collected in broader range of environments.

References

1. Cooper RA, Robertson RN, VanSickle DP, Langbein WE, and Fehr L, Wheelchair Injury Clinical Workstation: Method for Determining A Characteristic Stroke, Proceedings 15th Annual IEEE/EMBS International Conference, San Diego, CA, Vol. 15, No. 3, pp. 1294-1295, 1993.

2. Robertson RN, Cooper RA, Ensminger GJ, and Stewart KJ, Upper Extremity Net Joint Forces and Moments During Wheelchair Propulsion, Proceedings 17th Annual RESNA Conference, Nashville, TN, pp. 155-157, 1994.

3. Cooper RA, Robertson RN, VanSickle DP, A Recursive Back Propagation Algorithm for Computing Net Muscle Moments and Net Joint Forces, Proceedings 16th Annual RESNA Conference, Las Vegas, NV, pp. 277-279, 1993.

4. Ensminger GJ, Cooper RA, and Robertson RN, SMART^{wheeler}: A Clinical Workstation Interface for the Analysis of Wheelchair Propulsion, Proceedings 16th Annual IEEE/EMBS International Conference, Baltimore, MD, pp. 494-495, Vol. 16, 1994.

5. Cooper RA, Robertson RN, and VanSickle DP, Smoothing of Wheelchair Propulsion Kinematic Data, Proceedings 15th Annual IEEE/EMBS International Conference, San Diego, CA, 1993, Vol. 15, No. 3, pp. 1296-1297.

6. Asato KT, Cooper RA, Robertson RN, and Ster JF, SMART^{Wheels}: Development and Testing of a System for Measuring Manual Wheelchair Propulsion Dynamics, IEEE Transactions on Biomedical Engineering, Vol. 40, No. 12, pp. 1320-1324, 1993.

Acknowledgment

This work was supported in part by the US Department of Veterans Affairs, Clinical Workstation for Reducing Wheelchair Propulsion Injuries, B90-166A, and a NIDRR Training Grant, "Research Training in Engineering and Rehabilitation Technology," H133P3002-95.

David VanSickle
Human Engineering Research Laboratory
Veterans Affairs Medical Center
7108 Highland Drive, 151R-1
Pittsburgh, Pennsylvania 15206
TEL: (412) 365-4851
FAX: (412) 365-4858

BEST COPY AVAILABLE

JOINT KINETICS AND KINEMATICS FOR THREE SPEEDS OF WHEELCHAIR PROPULSION

Rick N. Robertson, Ph.D.[1,2,3], Sean Shimada, MS[2,3],Rory A. Cooper, Ph.D.[1,2,3], Greg Ensminger[3], MBE
[1]Division PM&R, University of Pittsburgh Medical Center, Pittsburgh, PA 15261
[2]Dept. Rehab. Science & Technology, University of Pittsburgh, Pittsburgh, PA 15261
[3]Human Engineering Research Laboratories, Highland Drive Veterans Affairs MC, Pittsburgh, PA 15206

ABSTRACT

The purpose of this study was to characterize joint moments and forces in the upper extremity for 3 speeds of propulsion and to relate these to joint kinematics. Two male experienced wheelchair users pushed a Quickie 1 on a dynamometer at 3 speeds of propulsion fitted with a force sensing wheel (Smart$^{\text{Wheel}}$ (1)). Kinematic evaluation of the shoulder in 2 planes (xy-sagittal, yz-frontal) and the elbow in 1 plane (xy-sagittal) were performed. Push rim forces and joint moments were determined in a method described previously (2,4). Results showed that subjects differed considerably in how they applied forces to the push rims in terms of maximum forces, time to maximums and the magnitudes of the force components. This study identified the places in the propulsive stroke where components of the force across the joints were high.

BACKGROUND

Wheelchair propulsion has primarily been studied by investigating the physiological demands placed on the user (7) and by describing the kinematics of the stroke (6). Very little work has been presented describing the kinetics of either push rim forces or joint moments and joint reaction forces (5). In order to prevent musculoskeletal injuries, increase efficiency and improve rider comfort an evaluation of the forces the wheelchair user applies to the push rim and the resulting joint forces must be made. Data has been presented which has characterized push rim forces for 3 different groups pushing wheelchairs (4). This work showed that experienced users produced lower levels of push rim forces and maintained them for longer periods of time. Additionally, push rim contact time was longer for this group, suggesting that joint kinematics differed. As an extension of this work, the present paper investigated 2 experienced wheelchair users propelling a wheelchair equipped with the SMART$^{\text{Wheel}}$ on the CSUS dynamometer (3) at 3 different speeds. In addition to push rim forces, joint moments were calculated in the sagittal plane and these were related to joint positions.The purpose of this study was to characterize the joint forces and to show the relationship between these forces and joint positions.

METHODS

Two experienced male wheelchair users with paraplegia, ages 24 and 33 years old, pushed a Quickie 1 wheelchair secured to a wheelchair dynamometer fitted with the 3-channel wheel (SMART$^{\text{Wheel}}$) on its right side at 3 speeds (average speed across subjects and strokes 1.73, 2.83, and 4.87 m/s) for 3 minutes at each speed. Data were collected at 60 Hz for approximately 10 complete strokes near the end of the 3 minutes. Processing of the signals from the beam-mounted strain gauges resulted in a determination of forces in the x and y direction and moment about the z-axis (x - anterior-posterior; y - superior-inferior; z - medial-lateral). An optical encoder provided information about angular motion of the wheel. Simultaneous video data were collected at 60 Hz from 3 cameras. Video data were synchronized with the force data utilizing a synchronization pulse. Subsequent calculations of joint moments were completed by combining kinematic variables, push rim forces and anthropometric data utilizing a method described by Cooper et al. (2). Joint angle data was determined from digitized values using a Peak 5 System (Peak Performance Technologies, Inc.). Data were analyzed for 3 complete strokes.

RESULTS

Pushrim forces. Subject 1 had mean peak Fx measures of 60.57, 69.96, and 113.97 N for the slow, moderate, and fast speeds, respectively. There were no significant difference ($p>0.05$) in peak Fx measures between the slow and moderate speed, although there were significant increase in peak Fx between the slow and fast and the

370

moderate and fast speed. Subject 2 showed no significant differences between the mean peak Fx values of 44.15, 78.88, and 76.97 N for the three increasing speeds. The mean time to peak Fx for subject 1 during the slow, moderate, and fast speed was 0.357, 0.360, and 0.210 seconds, respectively. For subject 2, the mean time to peak Fx was 0.353, 0.360, and 0.330 seconds, respectively. Subject 1 and 2 showed no significant differences in time to peak Fx and percent of stroke to peak Fx across the three increasing speeds.

For peak Fy, subject 1 had mean values of 48.91, 57.10, and 45.09 N for the slow, moderate, and fast speeds, respectively. There were no significant differences in peak Fy for subject 1 with increasing speed. Subject 2 showed no significant difference between mean peak Fy values of 27.37, 60.64, and 58.98 N for the three increasing speeds. The mean time to peak Fy were 0.373, 0.360, and 0.223 seconds, respectively for subject 1. Subject 2 had mean time to peak Fy values of 0.353, 0.377, and 0.317 seconds, respectively. Both subjects did not show a significant difference ($p>0.05$) in mean time to peak Fy and percent of stroke to peak Fy. There was a significant decrease ($p>0.05$) in total cycle time as trial speeds increased for both subjects.

Joint angles and pushrim forces. The shoulder xy-plane (sagittal) angle were at 123.9, 106.3, and 105.5 degrees for slow, moderate, and fast speeds, respectively, when peak Fx was reached by subject 1. Subject 1 did not show a significant difference ($p>0.05$) in shoulder angles in the xy-plane across speeds. Subject 2's shoulder angles were 105.7, 91.2, and 84.3 degrees for the three speeds, respectively, at peak Fx. Subject 2 showed a significant difference ($p<0.05$) across all three speeds, while a significant difference ($p<0.05$) was found between subjects. For peak Fy, subject 1 had shoulder angles of 122.7, 106.3, and 101.6 degrees for the three increasing speeds, while subject 2 had shoulder angles of 104.9, 90.1, and 90.3 degrees, respectively, at peak Fy. There were no significant differences ($p>0.05$) found in subject 1 and 2's shoulder angles (xy-plane) at peak Fy across all three speeds. Although, there were significant differences found between subjects at peak Fy.

The elbow angles at peak Fx for subject 1 were 104.1, 116.1, and 112.8 degrees for the slow, moderate, and fast speeds, respectively. There were no significant differences ($p>0.05$) in elbow angles across speeds. Subject 2 had elbow angles of 111.6, 117.4, 133.0 degrees for the increasing speeds, respectively. There were significant differences ($p<0.05$) in elbow angles across speeds for subject 2 and also between subjects.

At peak Fy, subject 1 had elbow angles of 103.8, 116.1, and 118.4 degrees for the three increasing speeds, respectively. Subject 2 had elbow angles measuring 113.3, 118.3, and 123.9 degrees for the slow, moderate, and fast speeds, respectively. There were no significant differences ($p>0.05$) in elbow angles at peak Fy across speeds and between subjects.

Joint moment-kinematic relationships. Figure 1A illustrates the relationship of elbow angles and elbow moments. Each graph contains three consecutive strokes beginning from hand contact, to the time when the hand leaves the pushrim. The elbow angle/elbow moment plots indicate the elbow beginning the push phase approximately at 120 degrees of elbow extension. Figure 1B illustrates the relationship between the shoulder angle in the xy-plane and the moment developed at the joint. In the shoulder-xy angle/shoulder moment plots, the shoulder begins at 140 degrees of extension, which is referenced from the horizontal axis. Both subjects showed peak moments in the early portion of the propulsion phase. After this time, the moments gradually decreased until the end of the propulsive phase.

The elbow angle-force plot in figure 2 illustrate a large increase of Fy values upon hand contact. The beginning of the propulsive phase is characterized by a large increase in the Fx and Fy pushrim forces with relatively small changes in elbow angle. A large decrease in force is noted after the peak forces are produced, which occur at the same time as large changes in elbow angle.

DISCUSSION

The kinetic data provided by the SMART$^{\text{Wheel}}$ measured the forces exerted on the pushrim in the Fx and Fy direction. The forces exerted on the pushrim in the Fx direction were measured in relationship to the horizontal axis. Across several strokes, mean peak values measured as low as

44.15 N for the slow speed and as high as 113.97 N for the fast speed. Higher Fx measures illustrate a more horizontally directed force applied to the pushrim. The forces measured in the Fy direction are exerted in reference to the vertical axis. Mean peak values ranged from 27.37 N to 58.98 N for the slow and fast speeds, respectively. The large vertical force upon hand contact could be due to the user ensuring that there is an adequate amount of frictional force to sufficiently propel the wheelchair. The large repetitive force exerted in the vertical direction can lead to decreased efficiency and may cause musculoskeletal injuries. Subjects exhibited considerable variability in the way they applied forces to the push rim resulting in variable patterns of joint moments and forces. Increased speed did not always result in higher force values or increased rates of force development. Individual differences must be taken into consideration when assessing the stresses imposed on the upper extremity during wheelchair propulsion. Repetitive loading of the joints over long periods of time must also be further explored. The results from this study provides pertinent information to better understand the mechanics of wheelchair propulsion. The information gathered from the study may help to optimize stroke techniques, improve performance, identify the causes of injuries, and develop injury prevention techniques that may be used in the near future.

REFERENCES

Asato KT et al. (1993) IEEE Trans. Biomed. Eng., 40(12):1320-1324.

Cooper RA et al. (1993) Proceedings 16th Annual RESNA Conference, Las Vegas, (pp. 277-279).

Cooper RA (1989) Proceedings of the 12th Annual RESNA Conference, New Orleans, (pp. 450-451).

Robertson RN & Cooper RA (1993) Proceedings of the 17th Annual Meeting of the American Society of Biomechanics, Iowa City, (pp. 202-203).

Rodgers MM et al. (1992) Proceedings NACOB II, The Second North American Congress on Biomechanics, (pp. 457-458).

Sanderson DJ & Sommer III, HJ (1985) J. Biomechanics, 18(6): 423-429.

Veeger HEJ et al. (1989) Scand. J. Rehab. Med. 21:197-203.

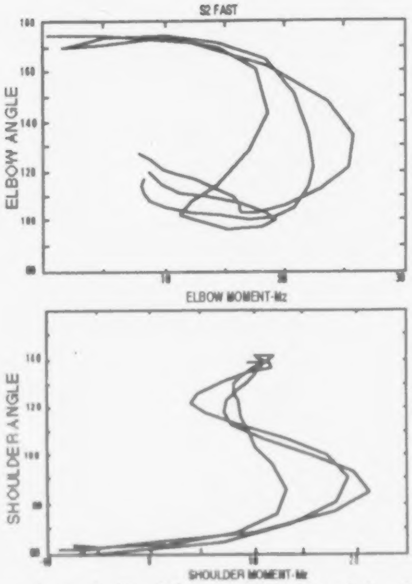


Figure 1 A & B. Joint angles plotted by joint moment for 3 strokes during the fast speed for subject 2.

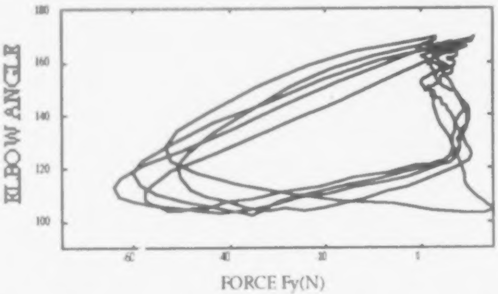


FIGURE 2. Elbow angle plotted by Fy pushrim forces for 5 strokes during the moderate speed for subject 2.

ACKNOWLEDGEMENTS

Partial funding for this research was provided by the U.S. Department of Veterans Affairs Rehabilitation Research & Development Services (Project #B686-RA) through the Edward Hines Jr. D.V.A. Hospital and the U.S. Department of Education, Rehabilitation Services Administration (H129E00005).

Rick N. Robertson, Ph.D.
Division Physical Medicine & Rehabilitation
University of Pittsburgh Medical Center
Kaufmann Building, Suite 901
Pittsburgh, PA 15213
TEL: (412) 648-6976
FAX:(412) 692-4410

CHARACTERIZATION OF UPPER EXTREMITY JOINT KINETICS DURING WHEELCHAIR PROPULSION

Rick N. Robertson, Ph.D.[1,2,3], Rory A. Cooper Ph.D.[1,2,3], Greg Ensminger, Michael L. Boninger, M.D.[1,2,3]
[1]Division PM&R, University of Pittsburgh Medical Center, Pittsburgh, PA 15261
[2]Dept. Rehab. Science & Technology, University of Pittsburgh, Pittsburgh, PA 15261
[3]Human Engineering Research Laboratories, Highland Drive Veterans Affairs Medical Center, Pittsburgh, PA 15206

ABSTRACT

This paper characterizes upper extremity joint moments and forces for 3 groups of subjects; categorized by gender and level of experience. At the wrist and shoulder a large vertical component of force was noted which may be a major factor in injury. Different groups of users based on gender and level of experience using a chair demonstrated differences in these forces produced across the joint. Changing the stroke mechanics of users or their fit to the wheelchair may have dramatic effects on the joint kinetics. These conditions when studied in relationship to the information provided in this paper will lead to the development of strategies by the clinician for reducing the incidence of manual wheelchair propulsion injuries.

BACKGROUND

Manual wheelchair propulsion is used as a means of mobility by approximately 1.2 million people in the US (9). The prevalence of upper extremity injury in the spinal cord injured (SCI) population using wheelchairs is high. Upper extremity injury among wheelchair users has been shown to be as high as 51% with shoulder problems (7), a 30% incidence of persistent, chronic shoulder pain was found during transfers (3), and upper extremity pain (5) and prevalence of Carpal Tunnel Syndrome (1,6) increased with greater years post injury.

The biomechanical consequences of repetitive overuse trauma could eventually lead to the injuries which prevent the manual wheelchair user from being able to push their chair. As a step in developing appropriate strategies for reducing the incidence of upper extremity injuries among wheelchair users, an assessment of forces at the major joints of the upper extremity needs to be made. Net joint moment and force calculations provide information related to the overall stresses being borne across joint structures.

Although a number of researchers (9) have studied pushrim forces, the lack of adequate instrumentation has prevented joint moments and forces from being determined. We have described a device (SMART$^{\text{Wheel}}$(6)) which allows the measurement of forces and moments applied to the pushrim and the location of the center of pressure (COP) (10); information which is necessary to determine joint kinetics. The present paper presents information on the joint moments and forces at the wrist, elbow and shoulder for 3 different groups of wheelchair users based on level of experience. This information will provide useful information as a first step in determining harmful stroke mechanics and for implementing effective rehabilitation protocols.

METHODS

Each of twelve subjects (4 male wheelchair users M-WCU, 4 male non-wheelchair users M-NWCU and 4 female non-wheelchair users F-NWCU) gave informed consent to participate in this study. Subjects were asked to push a Quickie 1 wheelchair (Sunrise Medical, Inc., Quickie Wheelchair), fitted with the Smart$^{\text{wheel}}$ (2) on the right side, with the chair secured to the wheelchair dynamometer (12). Subjects practiced pushing on the dynamometer until they were comfortable with the set-up. Each subject was then asked to push the wheelchair between 1.5 and 2.0 mph (.67 and .89 m/s). Subjects monitored their speed by viewing an analog tachometer mounted at the front of the dynamometer. SMART$^{\text{Wheel}}$ data were collected at 75 Hz per channel for approximately 10 complete strokes. Processing of the signals from the beam mounted strain gages resulted in a determination of forces in the x and y direction and moment about the z-axis (x - anterior-posterior; y - superior-inferior; z - medial-lateral). Video data were collected at 60 Hz from a right sagittal view of each subject. Video data was synchronized with force data. An interpolating spline was used to match video data to the 75 Hz force data. A Peak 5 System (Peak Performance Technologies, Inc.) was used to generate limb acceleration values following smoothing of the raw data utilizing a Butterworth filter with a 6 Hz cutoff.

Center of pressure (COP) on the push-rim was determined by a method described previously (10). The COP hand location on the hand was assumed to be at the 2nd MP joint. Inertial parameters for the hand, forearm and arm were estimated using data provided in the literature (13). The method described by Cooper et al. (4) was used to estimate net muscle moments and net joint reaction forces.

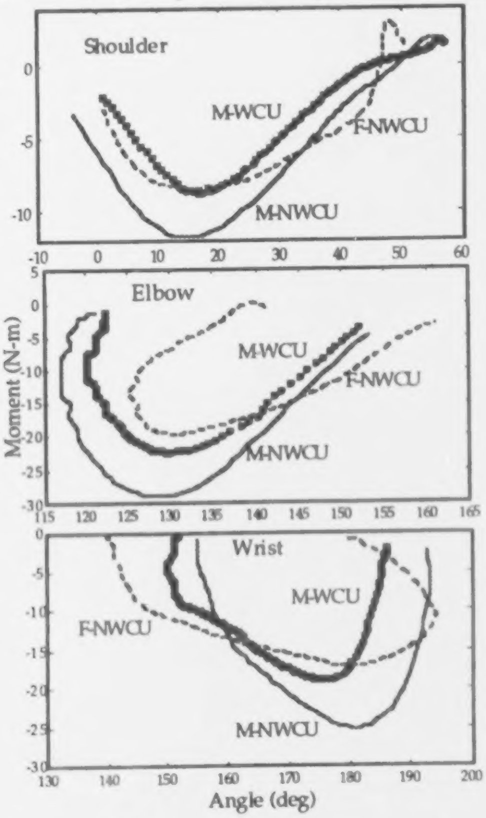


Figure 1. Mean joint angle-joint moment graphs for each group and joint.

RESULTS

Five strokes were analyzed for each subject. Figure 1 shows a plot of the mean joint angle by joint moment for each of the 3 groups. In order to combine the data, both the angle data and moment data were normalized by determining a value at each 1% of the propulsion phase, up to 100%. As noted from these graphs, there was considerable difference between groups in the magnitude of the peak moments, although these occurred at approximately the same joint position for all groups. At the shoulder this peak occurred just as the arm exceeded the vertical position by approximately 10 deg. At the elbow, the peak moment occurred at approximately 130 deg, referenced to complete extension as 180 deg. For the wrist, this peak occurred almost with the wrist in a neutral position for all groups (180 deg).

Figure 2 depicts plots of one component of the joint forces; Fy - vertical for all three groups normalized to 100% of the propulsion phase. Only plots of the wrist and shoulder are provided as these are the areas generally injured by manual wheelchair users. At the wrist and shoulder a large vertical component of force is noted. In fact, at the wrist the vertical component of the force was nearly double the horizontal component. The inexperienced male wheelchair users (M-NWCU) had a tendency to have larger forces in both directions and at both joints.

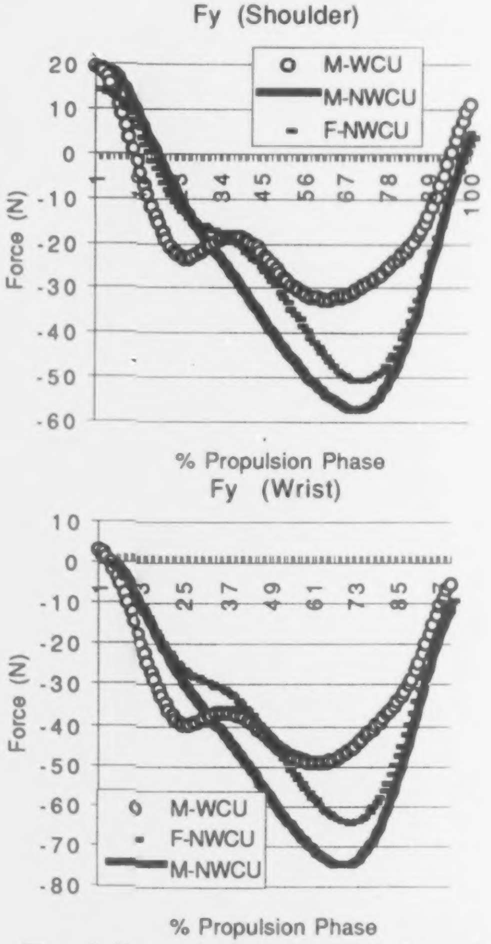


Figure 2. Verticle forces (Fy) at the shoulder and wrist for each group normalized to 100% of the propulsive stroke.

The rate of rise of the forces at the beginning of the stroke tended to be the same for all groups, but the experienced users (M-WCU) and the female inexperienced users (F-NWCU) tended to reduce the level of forces early in the propulsive phase.

DISCUSSION

Shoulder and wrist injuries have been reported by a large number of manual wheelchair users. The present study showed that an analysis of joint kinetics can provide information about the stresses being borne by joint structures during wheelchair propulsion. Different groups of users based on gender and level of experience using a chair demonstrate differences in these forces produced across the joint. It was noted that a large vertical component of force was present at both the wrist and shoulder. For the shoulder, this force has a tendency to drive the humeral head upward into the acromial shelf; a possible mechanism for the development of rotator cuff problems. At the wrist, this component may put carpal canal structures at risk and lead to the development of repetitive strain injuries. Changing the stroke mechanics of users or their fit to the wheelchair may have dramatic effects on the joint kinetics. These conditions when studied in relationship to the information provided in this paper will lead to development of strategies by the clinician for reducing the incidence of manual wheelchair propulsion injuries.

REFERENCES

1. Alijure, J et al. (1985) Carpal tunnel syndrome in paraplegic patients. *Paraplegia* **23**: 182-186.
2. Asato, KT et al. (1993) $\text{SMART}^{\text{Wheel}}$: Development and testing of a system for measuring manual wheelchair propulsion dynamics. *IEEE Trans. Biomed. Eng.* 40(12):1320-1324.
3. Bayley, JC et al. (1987) The weight bearing shoulder: the impingement syndrome in paraplegics. *J. Bone & Joint Surgery*. (AM) 69: 676-678.
4. Cooper, RA et al. (1993). A recursive back propagation algorithm for computing net muscle moments and net joint forces. Proceedings of 16th Annual Conference of RESNA, Las Vegas, NV, 277-279.
5. Gellman, H et al. (1988A) Late complications of the weight-bearing upper extremity in the paraplegic patient. *Clin. Orthop.* **233**: 132-135.
6. Gellman, H et al. (1988B) Carpal tunnel syndrome in paraplegic patients. *J. Bone Joint. Surg. [Am]* **70**: 517-519.
7. Nichols, PJR et al. (1979) Wheelchair user's shoulder? Shoulder pain in patients with spinal cord lesions, *Scandinavian Journal of Rehabilitation Medicine*. 11: 29-32.
8. Niesing, Ret al. (1990) Computer-Controlled Wheelchair Ergometer. *Medical & Biological Engineering & Computing*. **28**: 329-338.
9. Philips, L & Nicosia, A (1990) An overview... with reflections past and present of a consumer. *J. of Rehabilitation Research and Development*-Clinical Supplement No. 2: Choosing a Wheelchair System, 1-7.
10. Robertson, RN & Cooper, RA (1993). Kinetic characteristics of wheelchair propulsion utilizing the $\text{SMART}^{\text{Wheel}}$ Proceedings of the 17th Annual Meeting of the American Society of Biomechanics, Iowa City, Iowa, pp. 202-203.
11. Sie, I et al. (1992) Upper extremity pain in the post rehabilitation spinal cord patient. *Arch. Phys. Med. Rehab.* **73**: 44-48.
12. Vosse, AJ et al. (1990) Computer control of a wheelchair dynamometer. Proceedings RESNA 13th Annual Conference, Washington, D.C., June, pp. 59-60.
13. Winter DA (1990) Biomechanics and Motor Control of Human Movement, Second Edition, John Wiley & Sons.

ACKNOWLEDGEMENTS

Partial funding for this research was provided by the US Department of Veterans Affairs Rehabilitation Research & Development Services (Project #B686-RA) and the US Department of Education, Rehabilitation Services Administration (H129E00005).

Rick N. Robertson, Ph.D.
Division Physical Medicine & Rehabilitation
University of Pittsburgh Medical Center
Kaufmann Building, Suite 901
Pittsburgh, PA 15213
TEL: (412) 648-6976
FAX:(412) 692-4410

THE EFFECTS OF REAR WHEEL CAMBER ON PHYSIOLOGICAL AND PERCEPTUAL RESPONSES DURING SIMULATED WHEELCHAIR EXERCISE

Shelley M. Buckley, Yagesh N. Bhambhani and Helen M. Madill
Department of Occupational Therapy, Faculty of Rehabilitation Medicine, University of Alberta, Edmonton

ABSTRACT

The purpose of this study was to examine the effects of wheelchair camber on physiological and perceptual responses during propulsion. Three different rear wheel camber angles (0, 4, and 8 degrees) were studied during simulated wheelchair exercise at 2 kmh. A sample of 19 males (19-74 yrs) participated in one test session, consisting of 3 different camber trials, interspersed with rest periods. Physiological responses studied included: absolute oxygen consumption (AVO_2), heart rate (HR), minute ventilation (V_E), and respiratory exchange ratio (RER), Perceptual responses included: the rating of perceived exertion for central factors (RPEC), and the rating of perceived exertion for local factors (RPEL). The net energy cost (NEC) at each camber angle was calculated from the values of AVO_2 and RER. The results demonstrated that increased wheelchair camber significantly elevated physiological costs of propulsion, but not the perceptual stress.

BACKGROUND

The design and development of wheelchairs which maximize independence and meet the needs of individuals who use them is not a new concept. In addition to meeting the functional needs of individuals utilizing wheelchairs, it is important to consider how design factors influence the individual from physiological and ease of use aspects. It is likely that wheelchairs which minimize energy for propulsion are possibly the most functional. It is reasonable, therefore, to assume that wheelchairs which require more energy for propulsion may contribute to increased dependence on caregivers and healthcare, systems simply because the user finds the energy demands unattainable or excessive. A further assumption is that users may fatigue more easily with wheelchairs which require more energy, thereby reducing the energy reserves available for other essential or desired activities of daily living.

While wheelchairs have undergone substantial modification in recent years, it is particularly interesting to note that a majority of wheelchair design changes have been driven by the need for optimal sports wheelchairs for use in athletic activities for the disabled population. Despite the fact that the information generated has been valuable, it is difficult to extrapolate this information to the more sedentary, non-athletic population who tend to be the primary and largest group of wheelchair users.

One design feature which has received very little attention in research studies, is that of rear wheel camber angle. While a number of researchers have questioned the impact of rear wheel camber on the physiological and energy costs of propulsion, only one study has specifically examined this particular design feature(1). However, the researchers, while recognizing that changing camber angles would create different drag ratios, elected to "equalize" the resistance by altering the load conditions on the wheelchair during propulsion. This created an abnormal situation, whereby in reality, drag ratios will change, but load conditions imposed by the wheelchair user will not. Thus, the pure effect of an exclusive change in wheel camber angle has not been fully explored. It has been estimated(2) that a change in the camber angle of 10 degrees, would likely only alter the rolling resistance of a wheelchair by 5%. However, the effect that this change in rolling resistance may or may not have on the energy costs of propulsion has not been formally addressed.

RESEARCH QUESTION

The purpose of this study was to evaluate the effects of rear wheel camber on the physiological and perceptual responses during simulated wheelchair exercise.

METHOD

Sample: Nineteen healthy, sedentary males volunteered for this study. The subjects ranged in age from 19 to 74 years of age. The mean ± the standard deviations for age, height and weight were 46.7±8yrs, 71.5cm±8cms and 77.9±11kgs respectively. The sample pools consisted of the University of Alberta, and a number of organizations for retired and semi-retired individuals throughout the City of Edmonton. Subjects were non-wheelchair users, and had no previous experience with wheelchair propulsion. Subjects were eligible for participation in the study if they: satisfactorily completed a Physical Activity Readiness Questionnaire (modified to reflect the upper age boundary), completed an activity questionnaire, were not currently involved in any strength or fitness training programs, and provided informed consent. General demographic data were collected for each of the subjects.

Instruments: Four major instruments were employed during this study. They were: (a) a wheelchair (Quickie GPS, Sunrise Medical, California, USA) mounted on a customized roller system, (b) a Sensormedics Metabolic Measurement Cart (MMC) (Sensormedics 2900Z, Yorba Linda, California, USA), (c) Polar wireless heart rate monitors (Polar Key, Model PE3000, Kempele, Finland), and (d) Borg Scale of Perceived Exertion (RPE).

The wheelchair selected for this study was chosen on the basis of its adjustable camber settings of 0, 4, and 8 degrees. It is a high performance, rigid wheelchair, with a weight of 20.5 lbs. The same wheelchair was used throughout the study, in order to eliminate differences between wheelchairs. The wheelchair was mounted on a specially constructed, low friction steel roller system, with a circumference of 53 cm. An optical sensor mounted on the roller frame detected signals from the roller each time a strip of reflective tape crossed its path. This information was then transposed to a computer which interfaced with the wheelchair roller. The computer recorded revolutions per minute, and then calculated distance travelled and velocity by way of a customized computer program. The information was then visually displayed in the form of a speedometer on a computer monitor, so that the subject could view the screen while propelling the wheelchair. The roller system was calibrated with a Cateye odometer prior to the commencement of the study. The MMC was used to collect the following data: AVO_2, RER, and V_E. Calibration of the MMC was required prior to testing each subject. The MMC was calibrated using commercially available precision gases (16% O_2, 4% CO_2, balance N_2; 26% O_2, balance N_2). Volume calibration of the mixing chamber was conducted prior to testing by injecting a known volume of air , in accordance with the manufacturer's guidelines. Throughout the testing session, the physiological responses of the subjects were monitored continuously. A Polar wireless heart rate monitor was used to record HR. Perceived exertion was measured using the Borg Scale of Perceived Exertion. This scale was used to collect data on two perceptual variables: RPEC and RPEL.

Test Procedures: Camber testing order was determined randomly by having the subject draw lots from a box. The wheelchair camber angle was adjusted, and the wheelchair was mounted on the customized roller. The subject was then seated in the wheelchair, and seat height was recorded. Seat height remained constant relative to each individual throughout all camber testing sessions. Baseline physiological responses were monitored for 4 minutes while the subject remained seated. At the end of this period, a 5 minute, free-wheeling familiarization period, at the rate of 2 kmh, was given to the subjects. Following the familiarization, subjects were allowed to rest for 8 minutes, to allow responses to return to resting values. After the rest period, the first camber testing commenced. Three camber testing sessions were interspersed with 8 minute rest periods. During each camber session the subject propelled the wheelchair for 8 minutes 30 seconds, at a rate of 2 kmh. During the propulsion periods, physiological responses were continuously monitored. After 8 minutes of propulsion, the subject was asked to indicate central and local ratings of perceived exertion to the researcher. Camber angles were adjusted during the rest periods, and the wheelchair was remounted on the roller. The entire testing session took approximately 1 1/2 to 2 hours.

DATA ANALYSIS

Data were analyzed using a one-way repeated measures ANOVA. Significant 'F' ratios were analyzed using post hoc Scheffe' tests. The level of significance for all tests was set at .05.

A Bonferroni process was applied to minimize the possibility of a Type I error occurring.

RESULTS

The results obtained during this study demonstrated increasing physiological and energy costs of propulsion as camber angles increased. However, perceived exertion did not reflect a significant change with differing camber angles. A summary of the post hoc Scheffe' results is presented in Table 1.

Table 1: Comparison of Means for Selected Variables

Variable	Camber 0	Camber 4	Camber 8
Physiological Responses			
AVO2(ml/min)	541.6(85)	553.4(114)	643.7(152)*
HR(beats/min)	86(12)	87(11)	91(12)*
VE(L/min)	18.7(3)	18.8(2)	22.2(6)*
RER	9(1)	9(0)	9(1)
Perceptual Responses			
Variable	Camber 0	Camber 4	Camber 8
RPEC	8.7(1)	9.3(1)	9.2(2)
RPEL	9.6(2)	10(1 [illegible])	7.6(2)
Energy Expenditure			
Variable	Camber 0	Camber 4	Camber 8
NEC(kcals/min)	1.33(.3)	1.4(.4)	1.9(.7)*

* - denotes significant differences between 8 degrees when compared to either 0 or 4 degrees of camber

As can be seen, camber angles had a significant effect on AVO_2, HR, V_E, and NEC. In reviewing the post hoc analyses, it was noted that these differences were significantly elevated at 8 degrees of camber, when contrasted againgst 0 or 4 degrees. However, the differences between 0 and 4 degrees were not significant. Perceptual responses, however, demonstrate a significant change.

DISCUSSION

It has been hypothesized that increased camber leads to a greater mechanical advantage. It is reasonable, therefore, to assume that this would subsequently reduce physiological and energy costs. However, the results of this study indicate quite the opposite, rather, that increased camber angles actually increase physiological and energy costs of propulsion. This leads one to question whether the effects of changing the rolling resistance of the wheelchair actually negates and possibly supersedes any mechanical advantage that may be gained through the alteration of rear wheel camber angle. Additionally, it is important to consider the effects of increased camber angles on wheelchair users, who may be compromised medically and physically. It has long been a common assumption among clinicians that increased camber angle would make it easier for the wheelchair user to propel. However, the results of this study demonstrate that increased camber angle could actually demand greater physiological and energy reserves than the more neutral camber angles. If indeed this is the case, it is imperative that the individual's abilities be carefully evaluated prior to the prescription of a particular wheelchair with rear wheel camber.

It has been suggested that wheelchairs which use the least amount of energy are the most functional, and ultimately represent a lighter demand on caregivers. Therefore, if neutral camber angle reduces physiological cost, this should be a consideration in the prescription of wheelchairs for active users. Although the sample studied represented a more sedentary group, it would be interesting to examine whether similar trends occurred in wheelchair athletes, since endurance and output, as well as fatigue are important components of any sport. Despite the fact that increased rear wheel camber is believed to add stability to the wheelchair, it would be prudent to examine whether the stability gained outweighed the extra physiological costs.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the support of Steve Chipun, Sunrise Medical, Calgary, Alberta and Eco Medical, Edmonton, Alberta, CANADA.

Shelley Buckley MSc.
Faculty of Rehabilitation Medicine
University of Alberta,
Edmonton, AB, Canada T6G 2G4

REFERENCES

1. Veeger, HEJ., van der Woude, L. & Rozendal, R. (1989). The effect of rear wheel camber in manual wheelchair propulsion. Journal of Rehabilitation Research and Development, 26, 37-46

2. O'Reagan, J., Thacker, J., Kauzlarich, J., Mochel, E., Carmine, D. & Brant, M. (1981). Wheelchair dynamics. In Wheelchair Mobility 1976-1981 (pp. 33-41). Rehabilitation Engineering Center, University of Virginia.

BEST COPY AVAILABLE

SIG-10
Electrical Stimulation

DEVELOPMENT OF A FES SYSTEM FOR C4 TETRAPLEGIA

Brian T. Smith, M.J. Mulcahey, Randal R. Betz
Research Department, Shriners Hospitals for Crippled Children,
8400 Roosevelt Blvd., Philadelphia, PA 19152

ABSTRACT

The application of functional electrical stimulation (FES) to provide upper extremity function for people with C4 tetraplegia is under investigation. This abstract describes a FES system that allowed one individual with C4 function to coordinate stimulated lateral or palmar prehension with stimulated arm movements using contralateral shoulder position. In this way, with one shoulder motion an object could first be grasped and then brought to the mouth. With this system, the subject was able to grasp a milk carton or fork, bring them to his mouth to drink or eat, and release them onto a work surface.

INTRODUCTION

With the increase in the number of people living with spinal cord injuries (SCI) at or above the C4 level, there is a tremendous need for assistive technology that will allow these individuals the ability to perform everyday activities in an independent fashion.

Functional neuromuscular stimulation (FES) is an intervention that has yielded positive preliminary results providing useful upper extremity movements for those with C4 SCI. Nathan [1] used surface stimulation to provide hand grasp and wrist movement, employing a voice recognition system for control. Wrist splints augmented stimulation and a suspended sling stabilized the shoulder. Hoshimiya and colleagues [2] reported an FES system that used intramuscular stimulation controlled by two sip-and-puff sensors to control hand grasp and extend the wrist and elbow. A balanced forearm orthosis (BFO) was used to stabilize the shoulder and, when coupled with voluntary shoulder movements, to position the hand passively for hand-to-mouth activities.

This abstract describes the development of a FES system for C4 tetraplegia designed to provide stimulated upper extremity movements for hand-to-mouth activities [3].

METHOD

Subject

Subject JSV is a 17 year old male who sustained a spinal cord injury resulting in C4 tetraplegia. He is classified as Frankel A with a total motor index of 0. He has volitional shoulder shrug bilaterally via the trapezius and levator scapulae muscles and has good head control. According to strength-duration tests, all muscles in the right upper extremity with the exception of those innervated at C5 responded well to stimulation . The subject's rotator cuff muscles, the deltoids, biceps, brachioradialis, brachialis, and supinator were completely denervated and hence would not respond to stimulation.

The subject is competent in the use of mouthsticks for computer and video game activities. The subject is unable to navigate a BFO or mobile arm support because of poor proximal strength, endurance and control. He is dependent upon an attendant for all activities of daily living and set-up for mouthstick activities.

Implementation

Percutaneous intramuscular electrodes were implanted in the muscles denoted in TABLE I. Because the elbow flexor and supinator muscles were denervated, a transposition of the latissimus dorsi was performed to provide stimulated elbow flexion [3] and the extensor carpi ulnaris tendon was inserted into the radius to provide stimulated supination.

Muscles were stimulated using a charge-balanced, constant current, biphasic waveform with an amplitude of 20 mA, frequency of 17 Hz, and pulse durations from 0-200 usec. All muscles were exercised with stimulation for roughly 2 hours per day for 6 weeks before functional activities were initiated with FES.

FES Control

The control scheme is summarized here and described in detail elsewhere [4]. For this control strategy, contralateral shoulder position was used both to choose one of two stimulation patterns and to control stimulation proportionally. Shoulder position was calibrated to a command range (CR) from 0 to 100 with 0 representing a resting shoulder position and 100 the maximum elevation that could be attained comfortably.

TABLE I: Muscles Stimulated.

Position	Movement	Muscle Stimulated
ARM	Adduction	Pectoralis Major
ELBOW	Flexion	Latissimus Dorsi [3]*
	Extension	Triceps
FOREARM	Supination	Extensor Carpi Ulnaris**
THUMB	Adduction	Adductor Pollicis
	Abduction	Abductor Pollicis Brevis
	Flexion	Flexor Pollicis Longus
	Extension	Extensor Pollicis Longus
FINGERS	Extension	Extensor Digitorum
	Flexion	Flexor Digitorum Superficialis and Profundus

*Muscle Transfer ** Tendon Transfer

Pattern Selection

Two stimulation patterns were developed. Both of them were derived from the same template pattern designed to couple hand and arm movements to allow hand-to-mouth activities (Figure 1). The patterns differed only in their grasp configuration: one pattern provided lateral pinch (P1) and the other palmar grasp (P2). The arm movements within each pattern were identical. A stimulation pattern was chosen by lifting the shoulder to a height that corresponded to the desired pattern and maintaining that position for 3 seconds. P1 was selected by placing the shoulder between 20 and 40 percent of the CR (20<CR<40). For P2, the shoulder was raised to between 40 and 60 percent of the CR (40<CR<60). After 3 seconds at the desired level, a transitional state was entered that allowed the shoulder to be returned to the starting position (CR=0) for proportional control.

Proportional Control

As shown in Figure 1, grasp and arm movements were accomplished with one continuous motion of the contralateral shoulder. With the shoulder in the start position, the hand was stimulated in grasp extension, the forearm was stimulated to neutral and stimulated elbow extension brought the hand to the work surface. The user controlled stimulation for adduction of the arm in the first 10 percent of the CR. As the shoulder was elevated beyond CR=10, the hand was stimulated to maximum flexion and the elbow flexor remained inactive. As elevation was continued (CR>50) the hand remained in flexion and stimulation to the elbow flexor increased to maximum pulse duration (CR>90). Relaxing the shoulder from full elevation reversed the sequence. First, elbow flexion was ramped off allowing gravity to extend the elbow passively; then grasp flexion was ramped off and grasp extension ramped on to open the hand.

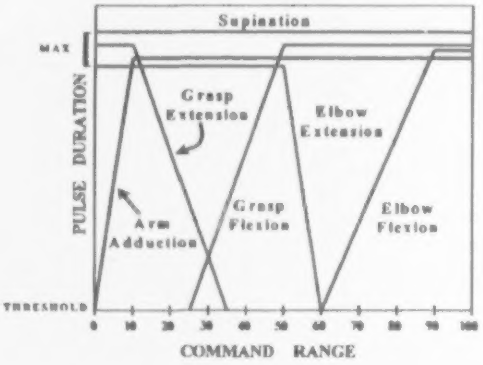


Figure 1: Template used to develop both stimulation patterns. Pulse duration as a function of shoulder position (command range).

Set-up

The subject was positioned in his power seating system reclined to 30°. His FES arm was positioned in 15° of shoulder abduction and was supported at the elbow and distal forearm with a suspended sling. A splint provided wrist stability. His left arm rested on a lapboard with the elbow at 90°. The shoulder position transducer was placed on the sternum with the telescoping rod attached to the left extremity at the glenohumeral joint. Audio and visual cues from the computer terminal relayed system status to the user.

Training

Over the course of 2 months, the subject participated in 10 one hour training sessions. The subject was trained to use the FES system for eating with a fork and drinking from a milk carton. Initial sessions were structured towards the completion of specific sub-tasks such as holding, lifting, etc. while in later sessions completion of the entire activity was practiced. Following training, the subject's abilities with FES were analyzed.

TABLE II: Eating with a fork.

Sub-Task	Able to do independently with FES?	Comments
Acquire	NO	Physical Assist
Hold	YES	
Stab	NO	Physical assist & adaptive utensil
Lift/Lower	YES	
Eat	YES	
Release	YES	

RESULTS AND DISCUSSION

With approximately 15^0 of contralateral shoulder elevation, the subject was able to select either stimulation pattern and control each one proportionally. As depicted in Table II, with P1 he could grasp a fork placed in his palm, bring it to his mouth to eat, return it to the work surface and release it. As shown in Table III, with P2 he could independently grasp a milk carton positioned in his open hand, bring it to his mouth, and drink using a short straw. He could also lower the carton to the work surface and release it independently, although not always in an upright position.

The ability to stab food or acquire the carton independently required arm movements such as forearm pronation and internal rotation which could not be accomplished volitionally and were not attempted with stimulation in this investigation. Further work is needed to develop stimulated movements or adaptive aids to allow these sub-tasks to be completed without assistance.

TABLE III: Drinking from a milk carton.

Sub-Task	Able to do independently with FES?	Comments
Acquire	NO	Assistance to stabilize and position carton
Hold	YES	
Lift/Lower	YES	
Drink	YES	With short straw
Release	YES	Not always in an upright position

ACKNOWLEDGEMENTS

The dedication of JSV to this project is greatly appreciated. This project was funded by Shriners Hospitals for Crippled Children Grant #15954.

REFERENCES

[1] R. H. Nathan, "An FES-based system for generating upper limb function in the C4 quadriplegic," *Med. & Biol. Eng. & Comp.*, vol. 27, pp. 549-556, 1989.

[2] N. Hoshimiya, A. Naito, M. Yajima, Y. Handa, "A multichannel FES system for the restoration of motor functions in high spinal cord injury patients: a respiration-controlled system for multijoint upper extremity," *IEEE Trans. Biomed. Eng.*, vol. 36, No. 7, pp. 754-760, 1989.

[3] R. R. Betz, M. J. Mulcahey, B. T. Smith, et al., "Bipolar latissimus dorsi transposition and functional neuromuscular stimulation in an individual with C4 quadriplegia and C5 denervation," *J. Amer. Para. Soc.*, vol. 15, no. 4, pp. 220-228, 1992.

[4]B.T. Smith, M.J. Mulcahey, R.J. Triolo, R.R. Betz. "Contralateral Shoulder Movement as an FNS Control Source for C4 Tetraplegics: A Case Report," *Proc. 15th Ann Conf - IEEE Eng Med & Biol Soc*, pp 1320-1321, San Diego, CA, 1993.

Brian T. Smith, Research Department
Shriner Hospitals for Crippled Children
8400 Roosevelt Blvd.
Philadelphia, PA 19152 (215) 332-4500 ext 254

THE EFFECTS OF INTRAMUSCULAR ELECTRICAL STIMULATION ON THE TEMPORAL GAIT CHARACTERISTICS OF A CHILD WITH SPASTIC DIPLEGIA: A CASE STUDY

Carolyn Barbieri Burns, Megan Moynahan, Randal R. Betz
Shriner's Hospital for Crippled Children, Philadelphia, PA

ABSTRACT

The purpose of this investigation was to determine the effects of an electrical stimulation exercise program on the gait characteristics of a child with spastic diplegia. Stimulation was delivered to selected muscles of the lower extremities through chronically implanted percutaneous electrodes using a research-grade stimulator. Variables measured include percent of the gait cycle spent in stance, swing, and double-limb support. Results showed statistically significant differences when comparing pre-exercise values to post-exercise values for all variables, with trends toward age-appropriate norms. These results suggest that intramuscular electrical stimulation, utilized as an exercise modality, may positively influence ambulation in some children with cerebral palsy (CP).

BACKGROUND

A variety of gait deviations in children with CP have been described. Abnormal timing and level of muscle activation have been indicated as major contributors to the gait deviations observed. Over the past 3 decades, electrical stimulation has emerged as a promising modality which has demonstrated the potential to coordinate the activation of several muscles simultaneously. Only recently has it's aptitude in this realm for the motor problems in CP been uncovered (1, 2, 3, 4, 5).

Electrical stimulation is the delivery of electrical current to tissues of the body for therapeutic purposes. Electrical stimulation has been studied in the population with CP for its effects on muscle strength (3), spasticity (6), range of motion (5), and gait characteristics (4). Stimulation may be delivered via surface, intramuscular, or epimysial electrodes. The vast majority of investigations using electrical stimulation have employed surface electrodes due to their non-invasive application, ease of removal, and commercial availability. Indwelling electrodes, though invasive, do offer several benefits over surface electrodes, including improved sensory tolerance, increased selectivity and ability to recruit deep muscles, and relative permanence of placement.

OBJECTIVE

The purpose of this paper is to report the results of a pilot study investigating the effects of an intramuscular electrical stimulation exercise program on the gait characteristics of a child with spastic diplegia. It is the first portion of a larger project investigating the automated delivery of electrical stimulation during the gait cycle.

METHODS

Subject

The subject (DSH) is a 6 year old male with a diagnosis of spastic diplegia associated with premature birth at 28 weeks gestation. His orthopedic surgical history includes bilateral heel cord lengthenings at age 3, prior to which he was non-ambulatory. Following this surgery, he ambulated with a reverse walker. At age 5, he progressed to bilateral forearm crutches, which he currently uses for school and community ambulation.

Qualitative Gait Analysis

Coronal and sagittal plane video tape records of DHS's ambulation were obtained for qualitative analysis. Gait deviations noted include excessive tone and compensatory movements of the upper extremities and trunk, poor pelvic control, Trendelenburg deviation, non-obligatory presence of primitive reflexes (ATNR and STNR), hip internal rotation and adduction, inadequate foot clearance during swing, poor ability to stop, start and change direction during ambulation, excessive knee flexion during stance, and poor dynamic balance.

Independent Gait Assessment

A pre-implantation assessment using a 3-D motion measurement system with surface EMG provided objective information on the subject's gait deviations and muscle activation which was used to identify the muscles that required stimulation. Muscles targeted for stimulation displayed inappropriate amplitude or timing of activation during gait.

Electrode Implantation

Bilaterally, the gluteus medius and maximus, vastus medialis and lateralis, medial and lateral heads of the gastrocnemius, and tibialis anterior muscles were implanted with percutaneous intramuscular electrodes.

Electrical Stimulation

Electrical stimulation was delivered from a 16-channel, portable, research-grade stimulator. Stimulation parameters were as follows: balanced, asymmetrical, biphasic pulse trains of pulse width 0-150 μsec, frequency 20 Hz, and amplitude 20 mA.

Two cyclical exercise patterns were developed. The first pattern exercised the bilateral gastrocnemius and tibialis anterior muscles in long sitting, while the second exercised the knee and hip extensors in standing. Exercise time over the 2 month trial averaged 15 minutes per day every other day for the calf exercise pattern, and 10 minutes per day every third day for the hip and knee extensor pattern. These values were obtained from automatic logging software contained in the stimulator.

Data Collection

Force sensing resistors (FSRs) were secured to the insoles of the subject's shoes so that the stance and swing phases of gait could be determined. The switches, placed under the forefoot and heel bilaterally, register force when they are compressed by the subject's body weight, signaling that the subject is in stance. Conversely, the switches register no force when the foot is in swing.

Data Analysis

Percent of the gait cycle spent in stance, swing, and double-limb support were determined over seven consecutive days pre- and one day post-exercise. Each data point represents the mean of six central step cycles within one 10-meter walk. The shaded areas on each graph represent 2 standard deviations (S.D.) around the mean of the seven pre-exercise data points.

RESULTS

Qualitative Gait Analysis

Several changes in DSH's gait pattern were noted following the stimulated exercise regime. Observational gait analysis revealed a decrease in excess trunk motions as well as a decrease in extraneous upper extremity movement during ambulation. DSH also had an improved ability to stop, start, and change walking direction without losing balance. Parent reports revealed ambulation as a new mode of mobility around the house, whereas prior to stimulated exercise, DSH relied on crawling.

Quantitative Gait Analysis

Figure 1 illustrates the percentage of the gait cycle spent in stance (Fig 1a), swing (Fig 1b), and double-limb support (Fig 1c) before and after exercise with the stimulation system. The seven pre-exercise measurements were collected on consecutive days, and represent the subject's day-to-day variability. The three post-exercise measurements were collected on the same day and represent the subject's walk-to-walk variability.

The 2 S.D. bandwidth method was utilized to determine statistical significance. All variables show a significant change in performance, as at least two consecutive post-exercise measurements fall outside the two S.D. bandwidth. Trends toward age-appropriate values (7) are clear, with a smaller proportion of the gait cycle being spent in stance and double-limb support, and a larger proportion spent in swing following stimulated exercise.

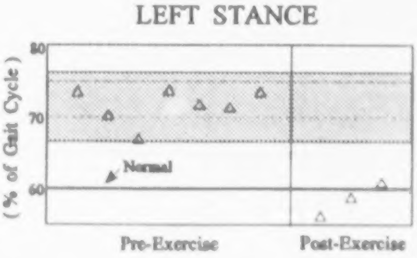


Figure 1a. Percentage of the gait cycle spent in stance before and after exercise with electrical stimulation.

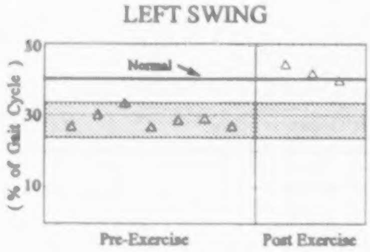


Figure 1b. Percentage of gait cycle spent in swing before and after stimulated exercise.

BEST COPY AVAILABLE

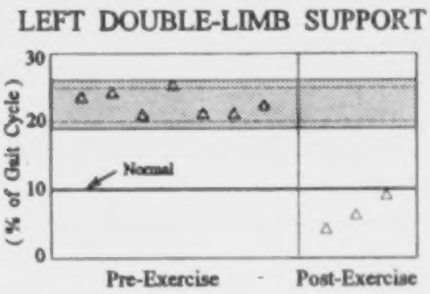


Figure 1c. Percentage of gait cycle spent in double-limb support before and after stimulated exercise.

DISCUSSION

Qualitative Changes in Gait

Although anecdotal changes in lower extremity voluntary strength, muscle control, and pelvic stability were noticed, no distinct change in DHS's ambulation level occurred. Prior to exercise with electrical stimulation DSH was classified as a limited community ambulator. DSH still requires forearm crutches to ambulate long distances. However, his parent's reported that following stimulated exercise, he preferred cruising to his previous crawling for household mobility.

Strengthening effects secondary to stimulated exercise are hypothesized to have caused the increased stance phase stability and reduced compensatory movements throughout the gait cycle, as determined by observational gait analysis.

Quantitative Changes in Gait

Quantitative changes in stance, swing, and double-limb support were measured and are thought to be the results of strengthening of key pelvic stabilizers. With increased pelvic and trunk stability, DSH demonstrated superior overall control, as measured by fewer falls during unaided ambulation. Further study of this intervention with additional children with spastic CP of varying involvement is now being undertaken.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge Esther Halden, Dolores Bertoti, and Meg Stanger for their assistance in this investigation. Elizabeth R. Gardner deserves special thanks as she designed the original protocol and laid the ground work for this study. Most importantly, we would like to acknowledge DSH and his family for their dedication to this project. This project was supported by Shriner's Hospitals research grant #15953.

REFERENCES

1. Gracanin F, Vrabic M, Vrabic G: Six years experiences with FES method applied to children. *Europa Medicophysica* 12:61-68, 1976.

2. Naumann S, Cairns B, Mazliah J, Milner M, Herbert M, Rang M: Therapeutic effects of electrical stimulation in spastic cerebral palsy. *In: Proc of RESNA 8th Ann Conf,* Memphis, Tennessee, 105-7, 1985.

3. Dubowitz L, Finnie N, Hyde SA, Scott OM, Vrbova, G: Improvement of muscle performance by chronic electrical stimulation in children with cerebral palsy. *Lancet* 1:587-588, 1988.

4. Carmick, J: Clinical use of neuromuscular electrical stimulation for children with cerebral palsy, Part 1: Lower extremity. *Phys Ther* 73:505-513, 1993.

5. Hazelwood M., Brown JK, Rowe PJ, Salter PM: The use of therapeutic electrical stimulation in the treatment of hemiplegic cerebral palsy. *Develop Med Child Neurol* 36:661-673, 1994.

6. Pape KE, Kirsch SE, Galil A, Boulton JE, White MA, Chipman M: Neuromuscular approach to the motor deficits of cerebral palsy: A pilot study. *J Ped Orthop* 13(5):628-633, 1993.

7. Murray MP, Drought AB, Kory RC: Walking patterns of normal men. *J Bone Joint Surg* 46A(2):335-360, 1964.

Carolyn Barbieri Burns, M.A.
Shriner's Hospitals- Philadelphia Unit
Research Department
8400 Roosevelt Blvd.
Philadelphia, PA 19152

BEST COPY AVAILABLE

LONG TERM STABILITY OF NERVE CUFFS IMPLANTED IN THE CAT FORELIMB

Kevin D. Strange, J. Andy Hoffer, Klaus Kallesøe, Sheila M. Schindler, David A. Crouch
Schools of Engineering Science and Kinesiology
Simon Fraser University, Burnaby, B.C., V5A 1S6, Canada

ABSTRACT

In two series of experiments, we chronically implanted a total of 56 nerve cuffs in the forelimbs of 14 cats. Each nerve was instrumented with a proximal stimulating cuff and a distal recording cuff, and we periodically monitored the status of the nerves and implanted devices over a total implant period of six months by stimulating the nerve and analyzing the resulting compound action potentials (CAPs) in the distal cuffs. Improvement in CAP amplitude and latency stability from the first series of implants to the second is demonstrated, as a result of improvements in surgical skill, quality of devices, and protection of hardware external to the cat. The longevity of neural recordings and implanted devices supports their implementation in human applications of functional electrical stimulation such as neural prostheses.

BACKGROUND

Recent advances in functional electrical stimulation (FES) systems have led to the consensus that closed-loop control of FES is both desirable and necessary for returning more efficient and normal-like function to paralyzed extremities. External sensors can be used to provide force and position feedback for neural prostheses systems, yet external devices are often inaccurate and difficult to position in the environment without external braces. An attractive approach is to utilize the natural sensors available in the extremities to retrieve contact, force, and position information from peripheral nerve and muscle recordings [1,2]. Recently, a novel clinical application of a closed-loop FES system to correct for drop-foot in a stroke patient implemented the use of cutaneous activity recorded from the Sural nerve with a chronically implanted nerve cuff as feedback [3]. This group has now also implanted a recording cuff on a human Palmar Digital nerve to retrieve contact and force information from the index finger (demonstrated at the Neural Prostheses: Motor Systems IV conference in Ohio, July 1994).

OBJECTIVES

Our overall objective is to identify reliable sources of neural control signals and extract features, such as ground contact and slip information, that may be applied in closed-loop FES systems for restoring voluntary use of paralyzed muscles in humans [4,5]. We are investigating both skin contact and limb position information obtained from nerve cuffs implanted on cutaneous and proprioceptive nerves in the cat forelimb during behavioural tasks.

Our objective for this study was to determine the stability of forelimb nerves of cats that were chronically implanted with stimulating and recording nerve cuffs over periods of six months.

METHODS

In a first series of implants, we implanted four nerve cuffs in the left forelimb of each of eight cats, two on the Ulnar nerve and two on the Median nerve, as shown in Fig. 1. Each nerve was instrumented with a proximal stimulating cuff above the elbow and a distal recording cuff below the elbow. We also implanted ground wires, a thermistor to record local limb temperature, and electromyogram (EMG) electrodes to record muscle activity in the Palmaris Longus, a primary wrist flexor. The wires were routed to a common percutaneous exit point and attached to a specially designed backpack containing a printed circuit board and a 40-pin connector.

In a second series of experiments, we implanted four cuffs in the left forelimb of six further cats, instrumenting two of the Ulnar, Median, and/or Radial nerves. In this series we also implanted EMG electrodes in two wrist flexors, the Palmaris Longus and the Flexor Carpi Ulnaris, and two wrist extensors, the Extensor Carpi Ulnaris, and the Abductor Pollicis Longus.

Our research animals were group-housed in a room that includes climbing shelves up to 2 m high and were freely allowed to jump and play. In order to simulate an implant in an active person, we did not attempt to control the physical duress applied to the implanted devices by restricting the cats' movement.

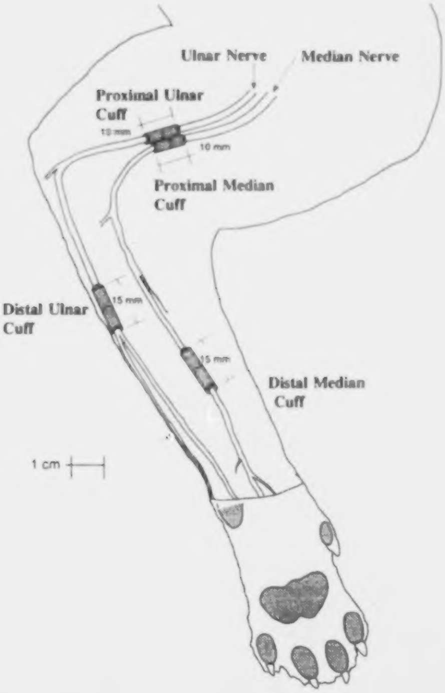


Figure 1: Medial view of the cat left forelimb with implanted nerve cuffs

Under halothane gas anesthesia, we periodically monitored the status of the nerves and implanted cuffs by stimulating the proximal nerve cuffs at supramaximal current levels and recording the compound action potentials resulting in the distal cuffs. We monitored the peak-peak amplitude of the CAP and the latency or conduction time between cuffs, both of which are indicative of the health of the instrumented nerve and viability of the nerve-cuff interface. We also monitored cuff electrode impedance and EMG pickup and recorded nerve and muscle data in the awake cat performing behavioural tasks.

Our surgical and experimental protocols were in accordance with guidelines set by the Canadian Council of Animal Care and were approved by the University Animal Ethics Committee.

RESULTS

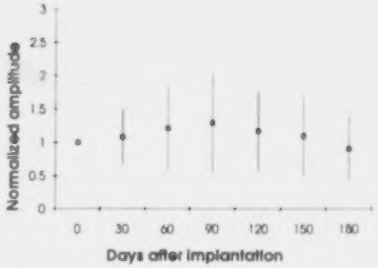


Figure 2: CAP amplitudes from first series of implants (normalized at day 0; n = 9; cats 2-6,8)

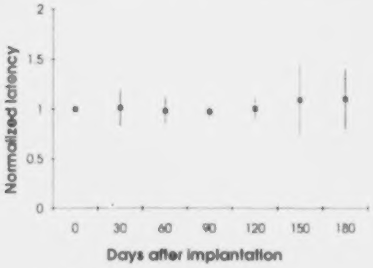


Figure 3: CAP latencies from first series of implants (normalized at day 0; n = 9; cats 2-6,8)

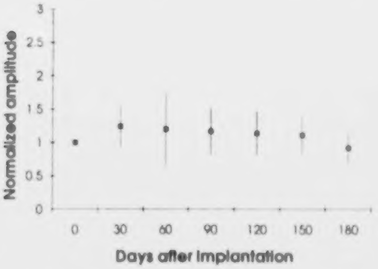


Figure 4: CAP amplitudes from second series of implants (normalized at day 0; n = 10; cats 9-14)

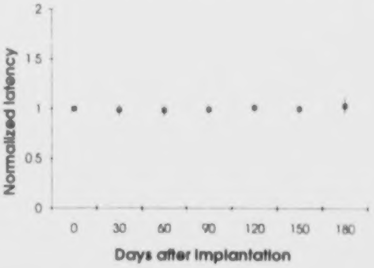


Figure 5: CAP latencies from second series of implants (normalized at day 0; n = 10; cats 9-14)

BEST COPY AVAILABLE

Long Term Stability of Nerve Cuffs

Figures 2 and 3 show the averaged CAP amplitude and latency data from the first series of cats. The CAP amplitude and latency data for each nerve monitored for longer than 180 days were interpolated to sampling intervals of 30 days. In the first series of implants, we successfully recorded from 9 nerves past 180 days, with the 7 failures resulting from pulled wires at the percutaneous exit point (5) and damage to the nerve (2). Both the average amplitude and latency data were stable throughout the implant period with maximum standard deviations of 57% (at day 90) and 33% (at day 150) respectively.

Figures 4 and 5 present the average CAP amplitude and latency data from the second series of implants. We recorded successfully from 10 nerves, with the two failures resulting from one case of pulled wires and a nerve compression injury. In the second series, the CAP amplitudes and latencies were even more stable than in the first series, with maximum standard deviations of 46% (at day 60) and 8% (at day 180) respectively.

DISCUSSION

Our results show that recording nerve cuffs can be implanted in the forelimbs of unrestrained cats for periods of at least six months without inflicting damage to the nerve, providing that 1) sufficient care is taken when surgically manipulating the nerve and installing the cuff, and 2) provisions are taken to prevent the cats from pulling and breaking wires. We attribute our greater success in the second series to both of these factors as we implemented an improved nerve cuff closing method which reduced trauma during surgery, and a fabric band around the belly of the cat which restricted access to the backpack connector and wires.

Future improvements in implantable nerve cuff designs in terms of mechanical interaction with the nerve and development of superior electrode materials and designs may improve the quality of neural recordings and longevity of recording nerve cuff applications. A further improvement in implantable device systems would be to utilize telemetry systems to avoid wire breakage inside the body or at percutaneous connectors.

Our demonstration of the stability and longevity of neural recordings in the cat forelimb lends support to including neural feedback in human applications of FES systems and neural prostheses.

REFERENCES

[1] Hoffer, J.A. Closed-Loop, Implanted-Sensor, Functional Electrical Stimulation System for Partial Restoration of Motor Functions. U.S. Patent No. 4,750,499, awarded June 14, 1988.

[2] Hoffer, J.A., and Haugland, M. Signals from tactile sensors in glabrous skin suitable for restoring motor functions in paralyzed humans. in *Neural Prostheses: Replacing Motor Function after Disease or Disability*, R.B. Stein, P.H. Peckham, and D. Popovic, editors. Oxford Univ. Press, pp. 99-125, 1992.

[3] Sinkjær, T., Haugland, M., and Haase, J. The use of natural sensory nerve signals as an advanced heel-switch in drop-foot patients. in *Proc. of the 4th Vienna Workshop on FES*, pp. 134-137, 1992.

[4] Haugland, M.K. and Hoffer, J.A. Slip information provided by nerve cuff signals: application in closed-loop control of functional electrical stimulation. *IEEE Trans. Rehab. Eng.*, Vol. 2, pp. 29-36, March 1994.

[5] Popovic, D.B., Stein, R.B., Jovanovic, K.L., Dai, R., Kostov, A., and Armstrong, W.W., Sensory nerve recording for closed-loop control to restore motor functions. *IEEE Trans. Bio. Eng.*, Vol. 40, pp. 1024-1031, Oct. 1993.

ACKNOWLEDGEMENTS

Funding for this research was provided the National Institutes of Health (contract number NIH-NINDS-NO1-NS-3-2380, J.A. Hoffer, P.I.).

Thanks to Paul Christensen, Yunquan Chen, Myriam El Mouldi, Catharine Kendall, and David Viberg for technical support.

Kevin Strange
School of Engineering Science
Simon Fraser University
Burnaby, B.C. V5A 1S6, Canada
(604) 291-5770, fax (604) 291-3040
email: strangea@sfu.ca

AN EIGHT-CHANNEL BIPHASIC STIMULATOR FOR FUNCTIONAL ELECTRICAL STIMULATION

Paul R. Christensen and J. Andy Hoffer
Schools of Engineering Science and Kinesiology
Simon Fraser University, Burnaby, BC, Canada

ABSTRACT

Fluid limb motion control produced with functional electrical stimulation (FES) requires accurate timing of current pulses independently delivered to various muscles as well as the ability to rapidly change the intensity and patterns of stimulation in response to changes in load, limb properties, or command signals [1]. In our laboratory we are studying ways to use feedback information contained in neural activity during active movements with the goal of restoring the voluntary use of paralyzed limbs. The stimulator that we have designed is an integral part of the research being conducted to mimic normal movement control. This paper presents the criteria that we employed to design an eight-channel, feedback-controlled biphasic stimulator. The design is a novel approach which incorporates digitally programmable resistors to control the current amplitude of the delivered waveforms.

BACKGROUND

The goal of a constant current stimulator is to deliver accurate and reliable current pulses to muscle or nerve electrodes so that the net delivered charge is known. By varying the amount of charge delivered, the number of motor axons recruited by a stimulus pulse can be controlled in order to change the muscle force. Waveforms with amplitudes in the milliamp range are necessary to stimulate intramuscularly, whereas currents in the microamp range are necessary to stimulate nerves directly.

A stimulator with multiple output channels is needed in order to program stimulation patterns that resemble the normal physiological stimulation patterns in muscles of interest. Individual muscles need to be stimulated at different frequencies to produce the desired joint torques. By using biphasic pulse stimulation, the charge delivered to the stimulating electrode can be balanced thus reducing toxic reactions at the tissue-electrode interface [2, 3]. The first pulse triggers an action potential within the axon, while a second pulse of opposite polarity, smaller amplitude, and longer duration balances the delivered charge.

The stimulator that we have designed can stimulate up to eight muscles or nerves simultaneously and allows independent on-line control of the width of every delivered current pulse.

STATEMENT OF THE PROBLEM

The stimulator that we required needed to be able to synchronize up to eight stimulation patterns and interchannel intervals and accurately produce the biphasic pulses needed for stimulation. The stimulator needed to deliver positive and negative polarity (i.e., biphasic) rectangular-shaped current pulses in the range 10 μA to 30 mA through a maximum impedance of about 15 MΩ. Successive pulses could have the same or opposite polarity, but would usually consist of a positive pulse followed by a negative pulse. Each channel was to be stimulated sequentially with a nominal frequency of 25 Hz per channel with pulse widths up to 2550 μ sec. The stimulator also needed to be flexible enough so that several users could apply it to their own specific purposes easily and quickly.

The new stimulator was to be programmable for use in a closed-loop configuration where the program could modify any of the stimulation parameters (frequency, pulse duration, pulse amplitude) once a control paradigm was determined. As an example, this paradigm may take the form of a state machine combined with a threshold function. If the recorded electromyogram (EMG), electroneurogram (ENG), or muscle force suggests that the limb is in some defined state, then the stimulator will change its output to make the limb take appropriate action. When the action is not appropriate, then the stimulator's output will be modified on the basis of ongoing feedback [1].

APPROACH

To enable a flexible system, we have utilized a 486 computer as the controller for the stimulator. The computer controls the channel sequencing and timing and operates as the user interface. From the user's point of view, the stimulator is comprised of a computer connected to the stimulator hardware (see Figure 1). The computer provides a mouse-driven interface that allows the user to select the number of channels to stimulate and to control the stimulation parameters.

We adopted a modular design which simplifies the realization of the circuitry. Each of the counter blocks comprising the timing circuitry has the same structure and all the current sources have the same design and layout. If any particular section of the stimulator board needs to be modified, then that section can be removed and replaced. For example, each current source is built on a separate card so that current sources may be easily replaced if this should become necessary.

SYSTEM DESIGN

The hardware section of the stimulator can be divided into the controlling computer, the interface and decoding circuitry, the timing circuitry, and the current source circuitry. The block diagram in Figure 1 shows the interconnections between the various sections.

The computer is responsible for the overall control of the system and the user interface. We programmed a 486 computer to act as the controlling computer and wrote routines in C with Borland's C++ 3.1 compiler to communicate with the stimulator hardware. The user interface for the stimulator was based upon an existing interface used previously in the lab [1]. The computer case also houses an Omega PC-CTR-20 Counter/Timer board that handles the gross timing between channels and a National Instruments AT-MIO-16F-5 acquisition board that interfaces with the stimulator board.

The interface circuitry receives four-bit data nibbles from the computer and stores them in latches and therefore acts as a virtual 32-bit wide control port: 16 bits of this port are reserved for control signals and the other 16 are reserved for load bytes to the counter chips to allow for fast loading into the counters. The 16 control bits are divided to select one of the eight channels, to control one of the four programmable resistors on the selected current source, to load the counters in the timer circuitry, and to set the polarity and range of the current pulses.

The decoding circuitry selects a current source for stimulation and selects a programmable resistor in one of the current sources to set the current amplitude.

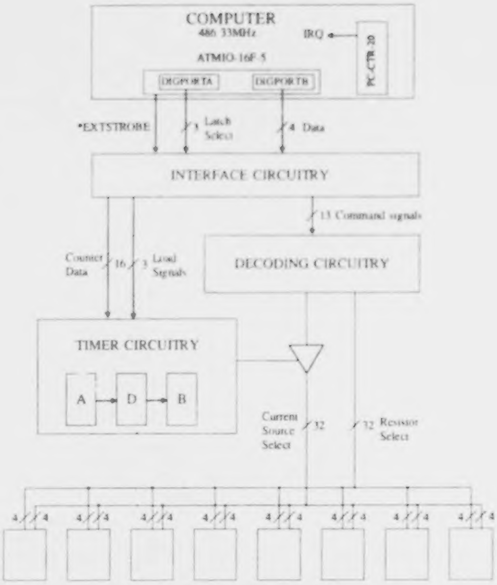


Figure 1: Stimulator block diagram

The timing circuitry controls the precise timing of the activation of the current sources to the nearest microsecond. When counter blocks "A" and "B" are active, they enable the command signal to the current source selected by the decoding circuitry. When these counters have finished counting or when the delay counter (counter D) is active, the command signals to the current sources are disabled.

The optically isolated current sources are located at the final output stage of the stimulator board and are connected to electrodes which stimulate nerves or muscles. When the command signal is asserted, the current source turns on producing a rectangular-shaped pulse that ends when the signal is deasserted. Four current sources compose each channel. Two current sources are necessary to obtain the full $3^1/_2$ decades of range of currents because the digitally programmable resistor itself (Xicor E^2POT X9C103P) only has 2 decades of range. One is designed to handle 10 µA to 1,000 µA in 10 µA steps, whereas the other is designed to handle 300 µA to 30 mA in 300 µA steps. We duplicated this pair of current sources to get the opposite polarity current pulse.

DISCUSSION

With digital control, the user knows the exact state of the stimulator. A configuration file may be created that stores a user's setup of the stimulator parameters (e.g., number of stimulating channels, pulse amplitudes and durations) and can be reloaded at a later time. The digitally programmable resistor values are known precisely and can be reconfigured identically each time the stimulator is used.

The stimulator has the ability to respond and adapt to incoming feedback signals. Pulse widths, amplitudes, and frequency of stimulation can all be controlled to ensure that the stimulated limb takes appropriate action.

With our stimulator, a user has the ability to independently control up to eight muscles. If the user's objective is to control movement about a joint, a software program will cause the stimulator to alternate the stimulation of antagonist muscle groups. Alternately, by stimulating both muscle groups simultaneously, antagonist muscle groups could be coactivated in order to increase the stiffness of the joint.

REFERENCES

[1] Haugland, M.K. and J.A. Hoffer. 1994. "Slip information provided by nerve cuff signals: Application in closed-loop control of functional electrical stimulation," *IEEE Transactions on Rehabilitation Engineering*. Vol. 2, No. 1, 29-36.

[2] McCreery, D.B. and W.F. Agnew. 1990. "Mechanisms of Stimulation-Induced Neural Damage and Their Relation to Guidelines for Safe Stimulation," in *Neural Prostheses: Fundamental Studies*, W.F. Agnew and D.B. McCreery, Eds. Englewood Cliffs, New Jersey: Prentice Hall.

[3] Mortimer, J.T. 1981. "Motor Prostheses," in *Handbook of Physiology, The Nervous System II: Motor Control*, V.B. Brooks, Ed. Bethesda, Maryland: American Physiological Society, 155-187.

ACKNOWLEDGMENTS

Funding for this project was provided by the NeuroScience Network of Centres of Excellence of Canada; Contract # NIH-NINDS-N01-NS-3-2380 from the Neural Prostheses Program, NIH (JAH, Principal Investigator); and a BC 21 summer award to PRC. We thank Dave Viberg and Dr. Yunquan Chen for guidance and advice in technical issues during the project and Kevin Strange and Klaus Kallesøe for input during the design phase of the project.

Paul Christensen
Schools of Engineering Science and Kinesiology
Simon Fraser University
Burnaby, BC V5A 1S6 Canada
(604) 291-5770 fax: (604) 291-3040
pchriste@sfu.ca

Powering Sensors with an Implanted FES System

Paul M. Meadows, M.S., Primoz Strojnik, Ph.D.
Alfred E. Mann Foundation for Scientific Research, Sylmar, California

ABSTRACT

A multichannel stimulation system based upon a cochlear implant has been developed. One of the unique features of this system is its capability to measure voltages on any of its 16 leads. This is accomplished with a six bit analog to digital converter and five amplifier gain stages. Measurements are telemetered to the extracorporeal controller of the system. Sensors could be employed to provide closed loop control of electrical stimulation using this system. The issues of power generation for use by such a sensor and the implementation of these features are the subjects of this discussion.

INTRODUCTION

The Clarion™ cochlear stimulator was developed as an orthotic device for the deaf. Its function is to stimulate the auditory nerve via an array of sixteen miniature electrodes distributed along the end of a single multiconductor electrode lead. The PULSAR™ implantable FES stimulator consists of the modified electronic circuitry of the CLARION™ cochlear implant, hermetically sealed into a ceramic case brazed to a metal band with a header that contains four quadruple feedthroughs. Seventeen four-inch long wires exit the cast epoxy header protecting the feedthroughs. Sixteen leadwires connected to the feedthroughs provide sixteen stimulation and/or sensing channels. The seventeenth lead is connected to the metal header and is used for an indifferent electrode. In-line connectors are used to extend the lead wires from the stimulator to the stimulating electrodes.

The implant package receives data and energy required for its operation from an external antenna via inductive coupling. A 49 MHz amplitude-modulated carrier is used to transfer data into the implant with an information transfer rate of 1.1 Mbit/sec. The same 49 MHz signal also supplies the power for the implant circuitry as well as for the stimulation current.

The data transferred into the implant are organized in "words", each of which is 9 bits long. Nine words in sequence constitute a "frame". The first eight words contain stimulus amplitude and polarity data. Eight bits of a word define the output current amplitude and the last bit defines the polarity. The "ninth word" in the frame contains commands that define stimulation parameters other than amplitude or polarity and also provides a means for setting the configuration and functionality of the implant.

Most ninth words are organized as three subwords defining three types of data: "function", "channel", and "value". The "function" may be a global one, common to all channels, or it may provide control for an individual channel, activate back telemetry, set the maximum output voltage, or define the stimulus pulsewidth. The "channel" subword defines the channel number to which the rest of the command refers. The "value" subword selects subfunctions of a major function and is interpreted in the context of the overall command in which it is embedded.

Finally, the frame terminates with a group of pulses that define the "frame pulse". Its occurrence defines both the end of the present frame and beginning of the next.

Backtelemetry

The implant communicates with the external device using a separate telemetry channel. It operates at 10.7 MHz and employs frequency modulation. It operates in two modes. In the first mode, the carrier is turned on as soon the implant receives both enough power for operation and a unique data string from the external control unit. The presence of this carrier signals the external device that the implant is operating correctly. If the implant detects an error in the forward transmission it turns off the backtelemetry carrier, forcing the external device to restart the initialization procedure.

The second mode is the data transmission mode. The implant circuitry contains an analog to digital converter circuit (A/D) that is connected, via a multiplexer, to a number of internal nodes of the circuitry. This mode is activated by specific ninth-word commands. Signals which may be monitored under control of these commands include the stimulus output voltages and currents as well as power supply levels. This feature also allows monitoring of electrode/leadwire impedance thus providing a means of system fault identification. Sensors attached to the PULSAR™ could also provide voltages related to the state of the sensor. Other ninth-word commands are used to turn the A/D converter on and off to conserve power, and to set the gain of the A/D preamplifier stages. Five different gains from x1 to x100 can be programmed. The A/D subsystem has 6 bits of resolution and at maximum gain, the resolution is 2 mV. Transmission of backtelemetry data is synchronized with the incoming frame pulses, with one bit of information sent per word time.

Output stages

There are eight identical output stages. Each one is a current source, or sink, that can provide currents between 2.4 mA and 6 mA. Under control of the ninth-word commands, each output stage can be configured as an isolated bipolar source/sink or as a dual monopolar source/sink against the indifferent electrode. Furthermore, any two electrodes of the 16 may be configured as an electrode pair. In addition, an internal discharge resistor can be connected across the outputs on each of the channels and each channel can be individually disconnected from the external electrodes. The coupling between the output stages and the electrodes is made via 1 uF coupling capacitors. These capacitors are absolute necessary to prevent any DC leakage currents from damaging either electrodes or tissue.

Sensor and Implant Integration

In order for a sensor to utilized by the implanted PULSAR^{TM} FES system it must be electrically connected to one of the stimulus output leads and have a reference connection to the indifferent lead. If the sensor has its own power source then this is the only connection necessary. If however the sensor requires external power, this may be supplied by a stimulus output lead.

If the outputs of the PULSAR^{TM} did not have series capacitors then 6 mA DC could be supplied to external sensor circuitry for short periods of time, limited only by the implant power supply capacitors. This would be inherently a dangerous condition as any leakage in the system could allow DC currents to be passed to exposed metalic components potentially causing corrosion and tissue damage. The only other option is to use the AC coupled stimulus pulses to generate power for the sensor. This has been achieved experimentally by using the symmetrical biphasic pulse generation capability of the PULSAR^{TM} to drive a full-wave rectifier bridge and storage capacitor.

The maximum pulse output from a single lead of the stimulator is 6 mA with a maximum voltage of about 10 volts using a 14 volt refresh voltage. In an FES application where pulses are being generated at a maximum frequency of 100 Hz with a combined phase duration of 1 mS, this means that this power supply could be refreshed with a 10% duty cycle. This means that significantly less than 0.6 mA continuous current is available to power a sensor and its conditioning circuitry.

The voltage across the sensor power supply capacitor would be determined by the refresh rate of the biphasic pulses, the output voltage of the stimulator and the rate at which power is used by the sensor circuitry. Voltage regulation should be considered in the sensor conditioning circuitry.

DICUSSION

With the limited amount of current available to the sensor circuitry only highly efficient sensor technology could be considered or methods of time multiplexing the power supplied to the sensor should be utilized. For instance, hall effect sensors typically have supply current requirements of 8 to 10 mA at 5VDC and could not be readily utilized without some method to control the duty cycle of the sensor. Efforts are currently underway to develop these sensor technologies and conditioning circuits at our facility to facilitate the integration of sensors for FES applications. Of primary interest are sensors which can measure angle and force.

References

P Strojnik, P Meadows, JH Schulman and D Whitmoyer, "Modification of a cochlear stimulation system for FES applications", Basic and Applied Myology, Vol 4(2), pp. 129-140, 1994.

Address inquiries to:

Paul Meadows, M.S.
The Alfred E. Mann Foundation for Scientific Research
12744 San Fernando Road
Sylmar, California 91342

COMPARISON OF TECHNOLOGY MATCH BETWEEN TWO TYPES OF FUNCTIONAL ELECTRICAL STIMULATION HAND GRASP SYSTEMS

Denise L. Brown, M.S., C.R.C. and Charles Merbitz, Ph.D.*
Counseling and Human Development Services, Kent State University, Kent, Ohio
* Psychology Department, Illinois Institute of Technology, Chicago, Illinois

Abstract

Efforts towards evaluating assistive technology are concentrated in the areas of use and functional gain. In this study person-specific variables associated with the degree of match between individuals with disabilities and assistive devices are evaluated. Two types of Functional Electrical Stimulation [FES] systems for improved hand grasp were evaluated using a technology match philosophy. Comparisons are made between demographic variables, personal perceptions and person-technology match characteristics with respect to version of FES device (percutaneous or implanted) and category of system use (users or persons only screened for the device). Results confirm the importance of person-specific variables such as perception of success and positive change, the device match characteristics of an individual's temperament and the overall impact of disability in the use of FES hand grasp technologies.

Introduction

A hand grasp system using FES has a primary goal of increasing independence in the lives of users. Independence has various definitions in rehabilitation (1), yet consumer rights advocates promote definitions where independence is assessed based on the unique needs of the end user. FES hand grasp systems have been evaluated using various functional assessments which focus on daily living activities (2). Little is known of the effect on quality of life or the psychosocial impact of such technologies (3). Assistive technology assessment historically has included percentages and reasons for use and abandonment, infrequently seeking to determine causal factors and person-centered aspects of technology use (4, 5, 6). In a health care environment concerned with quality service delivery, attention needs to focus on outcome evaluations that consider the individual with a disability as a consumer of the available technology services. This type of client-centered attention can benefit researchers by guiding them in developing new technologies with the confidence that their potential users' needs have been addressed.

Research Questions

The purpose of this study was to investigate the device match characteristics and feelings of success and personal change associated with the version of FES device and with the categories of use. Research questions included: 1) Do device match characteristics differ by type of FES system or status of use?; 2) Do users differ in personal feelings of change or success as the result of device use?; 3) What are the reasons for not using/opting not to receive FES for hand grasp?

Method

Persons with C5/C6 tetraplegia who used an FES hand grasp system (users) and those who were eligible but declined the hand grasp system (screeners) were compared. FES systems were deployed using a percutaneous electrode or a fully implanted neuroprosthesis, as developed by Case Western Reserve University, the Cleveland VA Medical Center and the Cleveland FES Center (7, 8).

Subjects were mailed a packet including surveys, an introduction letter and consent form. Included in the packet were instructions for subjects to utilize a reasonable accommodation to assist in responding to the questionnaires. Pre-stamped return envelopes were also provided. The surveying and research procedures were approved by the institutional review board.

Subjects

Fifty-five persons were identified from a list of individuals who had participated in research protocols for either the percutaneous and/or implanted FES hand grasp systems. A total of 18 surveys were returned, for a 33% total response rate. Of the 38 users identified, eight respondents had used a percutaneous system (out of 30 sent; a 27% response rate) and six respondents had used an implanted system (out of eight sent; a 75% response rate). In all, 17 screeners were identified. These were individuals who are physiologically and psychosocially appropriate for the device, had been offered the system, yet had opted not to participate in the research. Access to screening records was limited; the number available to participate ($n = 17$) was smaller than the available user population ($n = 38$). Since the initial research population of implant users were drawn from percutaneous users, some of the implant screeners were previously percutaneous users. Respondents for the screener group consisted of three implant and one percutaneous candidate (25% and 20% response rates, respectively).

Instruments

The Assistive Technology Device Predisposition Assessment [ATD-PA] consumer version is based on a model positing that the characteristics of the person, the milieu, and the technology need to be considered when matching a person with a given assistive technology (9). The ATD-PA consumer version consists of

52 Likert scored items (score range 1 - 5) and checklists in which the degree of consumer and technology match is evaluated through the comparison of subscores in the areas of Assistive Device, Temperament, Disability and Psychosocial Arena. The lowest subscore represents a problematic area in the match of a particular piece of technology at that point in time. In the Assistive Device area, higher scores reflect a greater degree of acceptance of the particular assistive device into a person's life. In this subscale and in the Psychosocial Arena area, the item relating to cost of the device was changed because of the research nature of the devices. High scores in the Temperament subscale indicate an increased personal autonomy and optimal acceptance/adjustment to disability. The Disability subscale includes functional capabilities, with higher scores indicating satisfaction with current abilities and little limitation due to disability. For the Psychosocial Arena area, higher scores indicate that resources and support are plentiful or not a concern, and that the individual is socially integrated rather than isolated. Inter-rater reliability and content and criterion-related validity have been established for the instrument (10).

The demographic survey included questions related to type and date of spinal cord injury, type of FES, occupation, reasons for not accepting the technology (screeners), ways the device could be changed, feelings of successful use or change because of use (users), and reasons for not using the system when available (users).

Results

The mean age of the population was 34.3 years ($SD = \pm 14$), 83% are male and 17% are female. The mean age at the time of spinal cord injury was 27.2 years ($SD = \pm 14$) and the mean years disabled was 7.28 ($SD = \pm 4.5$). Fifty percent of the population incurred their injury as a result of a fall, 11% as a result of a sports injury, and 39% as a result of a motor vehicle accident. Eleven percent of the subjects were employed or attending school part-time, 50% full-time and 39% were unemployed or not attending school. Twenty-eight percent ($n = 5$) of the respondents utilized the reasonable accommodation for their responses.

The results of the ATD-PA show that overall the Assistive Device area is most problematic to subjects ($n = 9$ as the lowest score) and the Temperament subscale is never problematic. Users expressed the Assistive Device as problematic ($n = 7$) and screeners were equally split between Assistive Device and Disability ($n = 2$; $n = 2$) as problematic areas. Planned comparisons were performed using ANOVA, chi-square and correlation coefficients on subscales, type of use, version of device and demographic variables. Statistical significance was set at alpha = .05.

When asked if they felt they had used their systems successfully, ten users responded "yes", three "no" and one "partially" (Table 1). Significant differences were found among those interpreting success in three distinct areas: the type of FES system used, $\chi^2(1) = 3.95$; $p \leq 0.05$; the means of the Assistive Device subscale, $F(1, 11) = 6.59$; $p = 0.026$; and the means of the Temperament subscale, $F(1, 11) = 10.21$; $p = 0.009$.

When users were asked if through using a neuroprosthesis they had changed, nine responded "yes" and four responded "no" (Table I). Significance was also found in two areas for those relating feelings of change as a result of FES use: the means to the Assistive Device subscale, $F(1, 12) = 7.496$; $p = 0.018$; and the means of the Temperament subscale, $F(1, 12) = 10.127$; $p = 0.008$.

Table I: Responses to Qualitative Questions

Responses	Total	
	Percutaneous	Implant
Feelings of successful use of FES		
Yes (10 responses *)	5	5
increased independence	1	2
increased function (ADL's)	1	4
No (3 responses *)	2	1
electrode problems	2	
Partial (1 response)	1	
Feelings of change through use of FES		
Yes (9 responses *)	5	4
more independ./less depend.	4	3
less disabled/more like 'self'	1	1
improved self-esteem	1	1
No (4 responses *)	3	1
same in function/ADL's	1	1

* not all responses shown

In response to how the neuroprosthesis could be changed to work better for them, users gave 31 suggestions and screeners gave four. The responses regarding reasons for not using the system included having no assistance with donning/doffing ($n = 7$), technical problems ($n = 11$), or not needing FES for an activity ($n = 5$).

Discussion

Although the Assistive Device subscale was found to be the most problematic area in match, it was not significantly different for users, screeners, or the version of the technology. Among users of FES hand grasp systems, those who were more accepting of the device and more fully integrated the device into their lifestyle felt they had positively changed because of its use and also felt successful with their devices. Among users, those who felt more autonomous and had a healthier emotional well being and personal outlook also felt more successful in use of FES, and felt they had positively changed as a result of use. Those with optimal acceptance and adjustment to their disability had feelings of positive growth and change as a result of using FES.

The differences expected between users and screeners were found in only one area. Those perceiving successful use were more likely to be implant users than percuatneous users. A reason that other differences were not found might be that the screener population was limited and those that did participate were biased towards positive responses. Respondents to a mailed survey are more likely to be motivated by more positive experiences than those refraining from participation.

Results reveal two areas significant to neuroprosthetic hand grasp use that are more important than the type of system being used. Personal perception of technology's influence and the degree of integration into one's lifestyle are related to perception of successful use and to perception of positive change. These aspects of successful match can be attributed to increased function and subsequent independence.

Although qualitative responses varied with the version of FES, significant differences were not found. This might be reflective of the nature of independence. Any perceived increase in independence is so much more than previously attainable or expected, that the degree or type of technological advancement is of little importance.

Users and screeners alike gave a variety of suggestions for changes. Specific suggestions directed to the research team included exerting less pressure on participants to use the system and having a treatment site more geographically convenient, both of which are inherent obstacles in any research involving rehabilitation technology. Reasons for not using the system were similar, yet also included disappointment that the system still did not provide enough independence or that there was no time for its use. Screeners' reasons for not participating indicated that they felt satisfied with their present state and perceived the benefits not worthy of pursuit.

Researchers and clinicians working with rehabilitation technologies designed to increase the independence of persons with disabilities can benefit from these results in understanding the more personal and individualized aspects of assistive devices. The individual goals and objectives of the consumer and the nature of a continuum of technology use are important in the design and implementation of assistive devices. Screening for appropriateness should not consist solely of physiological, rough estimates of need and related psychosocial criteria. Areas related to disability, the assistive device itself, an individual's temperament and psychosocial environment have been shown to influence technology use in general. More specifically, the aspects of the device and an individual's temperament have been shown to relate to the more personal aspects of change and success, areas not often considered in technology assessment.

References

1. Nosek, M.A., & Fuhrer, M.J. (1992). Independence among people with disabilities: I. A heuristic model. *Rehab Couns Bull*, *36*, 6-20.

2. Wijman, C.A.C., Stroh, K.C., Van Doren, C.L., et al. (1990). Functional evaluation of quadriplegic patients using a hand neuroprosthesis. *Arch Phys Med Rehab, 71,* 1053-1057.

3. Harvey, J.R., Bradley, M.B. et al. (1992). Psychological effects of functional electrical stimulation: A review of the literature. *J Neuro Rehab*, *6*(4), 203-208

4. Garber, S.L. & Gregorio, T.L. (1990). Upper extremity assistive devices: Assessment of use by spinal cord-injured patients with quadriplegia. *AJOT, 44,* 126-131.

5. Philips, B. & Zhao, H. (1993). Predictors of assistive technology abandonment. *Assist Tech, 5,* 36-45.

6. Scherer, M. J. (1990). Assistive device utilization & quality of life in adults with spinal cord injuries or cerebral palsy two years later. *J Applied Rehab Couns, 21*, 36-44.

7. Gorman, P.H. & Peckham, P.H. (1991). Upper extremity functional neuromuscular stimulation. *J Neuro Rehab, 5,* 3-11.

8. Keith, M.W., Peckham, P.H., et al. (1989). Implantable functional neuromuscular stimulation in the tetraplegic hand. *JHand Surg, 14A,* 524-530.

9. Scherer Associates (1991). *The Scherer MPT Model: Matching People with Technologies.* Webster, New York: Authors.

10. Scherer, M.J. (1993, June). *The Assistive Technology Device Predisposition Assessment: How Does it Measure Up as a Measure?* 70th Annual American Congress of Rehabilitation Medicine, Denver, CO.

Acknowledgements

A portion of this research was completed during attendance at Illinois Institute of Technology, Department of Psychology, and partially funded by the Rehabilitation Services Commission, Traineeship Grant No. H129E30004-94. Gratitude is extended to P. Hunter Peckham, PhD, Susan Wiegmann, PhD, Ronald Triolo, PhD, and Marcia Scherer, PhD for inspiration, guidance and assistance.

Denise L. Brown, MS, CRC
ACHVE Dept., Kent State University
310 White Hall
Kent, OH 44242
(216) 672-2662

BEST COPY AVAILABLE

CONTROL OF THE HAND INTRINSIC MUSCLES BY FUNCTIONAL ELECTRICAL STIMULATION

Richard T. Lauer, Kevin L. Kilgore, and P. Hunter Peckham
Case Western Reserve University, VA Medical Center, and MetroHealth Medical Center, Cleveland, Ohio

Abstract

Hand grasp can be restored to persons with quadriplegia using functional electrical stimulation. Improvement in hand grasp is hypothesized through the use of the intrinsic muscles. The dorsal interossei, the palmar interossei, and the lumbrical muscles are essential for the maintenance of a proper balance of forces across the joints of the hand. However, how these muscles act across the different joints is an area of some dispute. Therefore, the functions of these muscles were studied by directly recording the moments that are generated across each of the joints due to electrical stimulation. The moments generated by the first dorsal interosseous, the first palmar interosseous and the first lumbrical were observed in five able bodied subjects. The overall goal will enable us to incorporate the intrinsic muscles into a neuroprothesis.

Background

Functional electrical stimulation (FES) has been shown to provide controlled hand function to those individuals who have sustained a spinal cord injury at the C5 or C6 level. Electrodes are implanted in seven selected muscles, allowing for a graded electrical stimulus to be specifically applied. A preprogrammed grasp template controls the order and magnitude to which the muscles are activated. Overall control of the system is maintained by the user through an external sensor which converts remaining voluntary movement into a proportional command-control signal to control grasp opening and closing. Logic signals, also generated by user controlled movements, turn the system on and off, change grasp patterns, and lock and unlock the system[1].

The current implantable system allows the user to select one of two possible grasp patterns, palmar prehension (three-jaw chuck grip) or lateral prehension (key grip). Generation of these two grasps is accomplished by electrical stimulation of the extrinsic muscles of the hand (those muscles which are located in the forearm but act to control finger movement). However, it has been shown [2] that the use of the extrinsic muscles alone to extend the fingers, as used in the generation of the palmar grasp, results in an imbalance of forces across the joints of the finger. This imbalance produces "clawing" of the fingers (interphalangeal joint flexion and metacarpal phalangeal joint hyperextension) which is seen to some degree in all the neuroprothesis users. It has also been shown [3] that the finger intrinsics are responsible for maintaining a proper balance of forces across the joints of the finger, and are essential for proper functioning of the hand, although their specific functions are in dispute.

Research Question

The aim of this study was to determine the functioning of each of the intrinsic muscles of the hand. The moments generated across the finger joints were measured to develop a quantitative description of these muscles. This information can then be used to make an informed decision as to which muscles should be incorporated into the neuroprothesis.

Methods

Subjects. This study was performed with five able bodied subjects who ranged in age from 22 to 50. These subjects were selected since there would be no atrophy of the intrinsic muscles or possible loss of innervation which would make electrical stimulation of these muscles difficult.

Finger Moment Transducer. A device was developed to measure the moments generated about the MP, DIP and PIP joints of the hand. The design (Figure 1) utilizes a parallelogram construction similar to that developed by Long [4] and Thomas[5] that allows the device to fit different sizes of hands. Aluminum uprights, fitted with strain gages, were attached to each joint segment providing the measurement of isometric moments generated about the MP, PIP and DIP joints of a single digit. Ball bearing joints between the upright beams and the parallel crossbars prevent hysteresis as well as provide a linear relationship between the value measured by the strain gages and the applied moment. Four of these devices can be used to make simultaneous measurements of all the moments generated about all three joints of the four fingers. Each joint can be positioned and locked at any angle throughout the range of motion of the joint.

Intrinsic Muscles

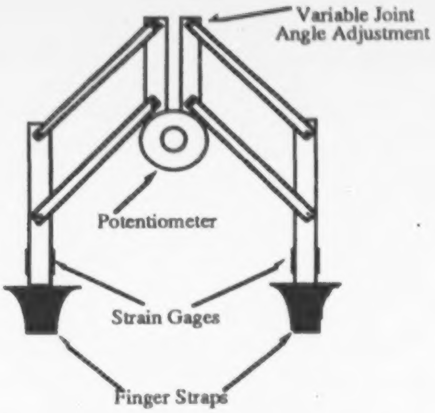


Fig. 1 - Finger Moment Transducer representing implementation for a single joint

The current experiments were performed with a two joint prototype, since the final device was under fabrication. In this case, uprights were attached to the hand to record the moment generated about the MP joint of the index finger in the flexion/extension direction and in the abduction/adduction direction. The repeatability of the moment measurements was less than 0.85 N cm and the error was less than 1% in the +/- 60 N cm measurement range. The error in the device increased to less than 2% in the +/- 100 N cm range, the maximum range allowable for this device.[6]

Additional Hardware. Surface electrodes were used for the electrical stimulation of the intrinsic muscles. A portable stimulation unit, modified for surface stimulation was used for activation of the muscles. The amplitude of the pulses were set at 20 mA and the stimulating frequency was set at 16 Hz to insure a smooth and continuous contraction. The stimulation pulse width was changed through a custom interface FES hand grasp software running on a 486 PC. Data collection was accomplished through a program written in LabVIEW running on a Macintosh IIfx computer. The analysis of the data was done through the use of Igor 1.24 on the Macintosh.

Experimental Protocol. The subject was seated comfortably with their left arm resting on a raised platform. A commercial portable surface stimulator was used to locate the motor points for the first dorsal interosseous (1DI), the first palmar interosseous (1VI), and the first lumbrical. Once located, electrodes were placed on these motor points and the threshold and maximum stimulus level were determined. The left hand was then placed in the finger moment transducer and the hand was locked into an anatomically neutral position. Each muscle was then stimulated in turn, starting at threshold and increasing in steps of 5μs until the maximum level was attained. Each muscle was stimulated for 5 seconds, with a minute of rest between each trial to prevent fatigue. For two of the subjects, the effect of joint angle on the generated moment was also measured by first flexing the MP joint and repeating the trials and then flexing both the MP and PIP joints and repeating the trials in the manner indicated above.

Results

Moment as a Function of Joint Angle. The effects of changing joint angle on the first dorsal interosseous for one of the subjects is presented in Figure 2. The top graph shows that the moment generated in the flexion direction decreased as the finger was flexed. This was due to the shortening of the extensor aponeurosis, which has the effect shortening the moment arm for the muscle acting in this direction. The change in the moment generated in the abduction direction was minimal since flexion of the finger does not change the insertion of the muscle into the lateral tubercle on the base of the first phalanx.

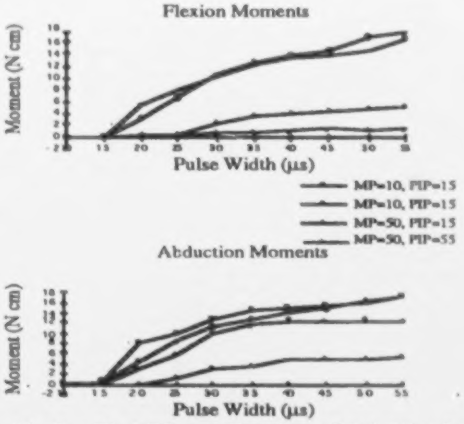


Fig 2. - First DI as a Function of Joint Angle

The same effect was seen in the first palmar interosseous. As the finger was more fully flexed, the moment in the flexion direction decreased because of its insertion into the extensor aponeurosis. However, since the insertion of the first palmar interosseous is not divided like it is with the first dorsal interosseous, the moment in adduction also decreased with finger flexion. We were unable to

BEST COPY AVAILABLE

make observations on the effect of joint angle on the moment generating capabilities of the first lumbrical. This was because its origin is on the tendon of the flexor digitorum profundus and finger flexion moved the muscle away from the stimulating electrode, thus preventing excitation.

Action of Muscles Across the MP Joint. The moments measured in abduction/adduction and flexion with the hand in the anatomically neutral position can be combined to produce a vector showing the line of action of the muscle. The results for one subject are shown in Figure 3. Only threshold, a middle value, and maximum stimulus level are shown since these values adequately demonstrate the trend in muscle recruitment.

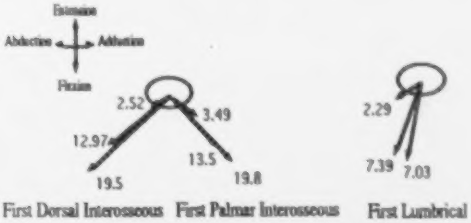


Fig. 3 - Muscle Action with Increasing Pulse Width

A two step recruitment pattern was observed with the interossei in all subjects. The muscles first acted primarily in abduction/adduction, with a gradually increasing flexion component with increasing pulse width. The lumbrical was observed to be primarily a finger flexor, although weak in its moment generating capabilities. An abduction moment was also noted, but is most likely due to spill over into adjacent muscle, since anatomical and EMG studies do not support the idea of the first lumbrical being a finger abductor.

Discussion

The study presented here provides direct measurement of the functions of the intrinsic muscles acting on the long finger. Anatomical studies and EMG recordings can provide information on when a muscle is active or how a muscle can possibly act, but only by studying the moments each muscle is capable of generating can a full understanding of the muscle be gained. From this study, it was shown that the first palmar and dorsal interossei are not only very strong abductors/adductors, but that they also generate a significant moment for MP flexion. Also, it was shown that the lumbrical is primarily a flexor of the MP joint, at least on the index finger, but its overall contribution to MP flexion is quite weak. This supports anatomical studies which suggest that the lumbrical only contracts in order to redirect passive forces in the extensor aponeurosis during certain movements.

This knowledge can be applied to possible incorporation of the intrinsics into a synthesized hand grasp. Although the lumbricales would be an ideal choice to correct MP hyperextension because they act purely as finger flexors. the muscles, as observed in this study, may not generate significant torque to be of any use. The results show that the interossei are better candidates for incorporation into a synthesized hand grasp. However, the results also indicate that both sets of interossei must be incorporated in order to counteract the abduction/adduction component of the muscles while providing a strong MP flexion moment to correct MP hyperextension.

References

1. Keith MW, Peckham PH, Thrope GB, Stroh KC, Smith B, Buckett JR, Kilgore KL, Jatich JW. Implantable functional neuromuscular stimulation in the tetraplegic hand. J Hand Surg,14A:3,524-530,1989.
2. Landsmeer JM. The co-ordination of finger joint moments. J Bone Joint Surg Am,45A,1654- 1662,1963.
3. Landsmeer, JM. Studies in the anatomy of articulation I: The equilibrium of intercalated bone. Acta Morphol Neerlando Scandin,3,287-303,1960.
4. Long C, Brown EB. Electromyographic kinesiology of the hand: Muscles moving the long finger. J Bone Joint Surg Am,46A,1683-1706,1964.
5. Thomas DH, Long C. An electrogoniometer for the finger: A kinesiologic tracking device. Am J Med Elect,3,96-100,1964.
6. Kilgore KL, Lauer RT, Peckham PH. A transducer for the measurement of finger joint torques. Proc. of 16th IEEE-EMBS Conf., 938-939,1994.

Acknowledgments

This work is supported by the NIH Neural Prosthesis Program, NIH Contract N01-NS-2-2344.

Address

Richard T. Lauer
MetroHeatlh - Rehabilitation Engineering Center
Hamann 601
2500 MetroHeatlh Drive
Cleveland OH 44109-1998
rxl26@po.cwru.edu

TRANSFER FUNCTION IDENTIFICATION BETWEEN MUSCLE TORQUE AND STIMULUS IN ELECTRICALLY ACTIVATED KNEE MUSCLES

M. Ferrarin[1,2], P. Iacuone[1], P. Baglioni[2], A. Mingrino[1,2], C. Frigo[1,2]
[1]Dipartimento di Bioingegneria, Politecnico di Milano, Milano, ITALY
[2]Centro di Bioingegneria, Fnd. Pro Juventute IRCCS-Politecnico di Milano, Milano, ITALY

ABSTRACT

The main goal of this work is to define the relation existing between the main parameters of the electrical stimulation and the characteristics of the muscle torque about the knee joint, in order to find the 'optimal muscle contraction' under dynamic conditions. A non linear first order model was used, whose parameters were identified from kinematic data collected during the pendulum test. Trials were performed in seven subjects.

INTRODUCTION

The Functional Electrical Stimulation (FES) allows patients with functional disorders derived from a spinal cord lesion to restore some motion activities through the generation of an electrical stimulus at a peripherical level that artificially supply to the physiological stimulus. The relations existing between the stimulation parameters and the induced movement are still to be defined. This is due to the high number of the variables that have to be considered. The control variables are the stimulation signal acting on a muscle or on a group of muscles, and the articular moment originated. The purpose of this study is the determination of the relation existing between the main stimulation parameters and the characteristics of the articular moment of the muscle stimulated in order to optimize the stimulation pattern.

The work is divided into two main phases: in a first phase, a passive pendulum test was performed in order to estimate the unknown parameters of the visco-elastic joint model; in the second phase, the rectus femoris muscle was stimulated and resulting torque about the knee joint was computed using kinematic data acquired during the movement. The data were used to estimate a transfer function between the electrical stimulus and the generated torque. Four healthy and three paraplegic subjects were analysed.

METHOD

The dynamic model developed to schematize the knee joint and its mathematical formulation is represented by the following equation of motion:

$$J\ddot{\Theta} = -mgl \cdot \sin(\Theta_{rv}) + \lambda \cdot e^{-E\Theta}(\omega - \Theta) - B\dot{\Theta} + Me$$

where:

J = inertial moment of shank-foot complex;

Θ = flexion/extension knee angle defined as the angle between shank and thigh;

$\dot{\Theta}, \ddot{\Theta}$ = angular velocity and acceleration;

m = mass of shank-foot complex;

g = acceleration due to gravity;

l = distance between the knee and the centre of gravity of shank-foot complex;

Θ_{rv} = angle between shank and vertical axis;

λ, E = elastic coefficients;

ω = resting elastic knee angle;

B = viscous coefficient;

Me = torque due to electrical stimulation.

The kinematic variables were computed from the data collected using the ELITE motion analysis system [1]. The anthropometric parameters J, m and l were estimated using Zatsiorsky regression equations [2], while B, λ, E and ω were derived from preliminary identification procedures consisting of passive pendulum tests [3,4] performed at the level of the knee.

The electrostimulator used is a programmable stimulator developed at the Bioengineering Unit of Strathclyde University [5], a constant current pulses generator with the following characteristics:

pulse amplitude: <150 mA;
pulse width: 20-500 μsec;
pulse rate: 20-50 Hz;
shape: rectangular.

In order to generalize the procedure, we used two different stimulation patterns, a step one and a ramp one; each applied at a frequency of 20, 25, 33 and 50 Hz and at a constant amplitude. Torque due to electrical stimulation was computed by substituting the values determined from the data acquired during the muscle stimulation into the following equation:

$$Me = J\ddot{\Theta} + mgl \cdot \sin(\Theta_{rv}) - \lambda \cdot e^{-E\Theta}(\omega - \Theta) + B\dot{\Theta}$$

Finally, through a parametric identification procedure based on an ARX model, we estimated a transfer function between stimulus and induced torque.

We found that a simple single-pole transfer function with frequency-depending gain can sufficiently well fit the data.

RESULTS AND DISCUSSION

Visco-elastic parameters (λ, E, B and ω) were computed for each of the seven subjects based on ten different trials of pendulum test; results are shown in table 1:

subject	age	λ	E	B	ω
CM	27	3.6644	-.0196	.4154	2.7553
AG	27	1.2	-.5066	.3973	2.5206
JL	27	4.2163	-.0094	.3446	2.4547
IP	26	4.1359	.2041	.3171	2.7206
VA*	25	16.474	1.6793	.2904	3.9132
DP*	30	26.795	1.6738	.2719	2.7383
SM*	32	3.8439	.07509	.3667	2.9892

***Tab 1**: Visco-elastic parameters of 4 healthy and 3 paraplegic subjects (*).*

The transfer function between stimulus and induced torque was obtained using a parametric identification procedure performed with an ARX model [6].

To choose the best ARX model describing the stimulus-torque relation we used Rissanen criteria, known as MDL (Minimum Description Length) method.

The identification was performed considering as input the stimulus shape (step or ramp) for each stimulation frequency and as output the depending torques. The contraction and relaxation phases (extension and flexion of the knee) have been considered separately.

In this way we obtained the following single pole transfer function:

$$H(s) = \frac{G}{1 + s\tau}$$

where:

τ = time constant of the pole;

G = static gain.

From the results it was possible to determine the indipendence of the poles from the frequency. It was then possible to utilize the value of the poles averaged at the different frequencies. This is not valid for different pattern of stimulation, where statistically significative differences between step and ramp were found.

The results obtained during the contraction and relaxation phases are shown in table 2 and 3.

Healthy	CM27	AG27	JL27	IP26
Step	-2,0362	-2,4749	-2,5220	-2,2269
Ramp	-1,3669	-1,1205	-0,5813	-0,5578
Parapl.	VA25	DP30	SM32	
Step	-4,6157	-1,1007	-5,4917	
Ramp	-1,0116	-0,1426	-2,0901	

***Tab2**: Poles computed during the contraction phase*

From the table 2 it is evident that the dinamic of the step pattern and of the ramp pattern are different during the contraction phase, when the step pattern is faster (bigger poles) than that of the ramp.

Healthy	CM27	AG27	JL27	IP26
Step	-6,5933	-5,0524	-4,9965	-5,9461
Ramp	-5,5018	-3,7736	-5,3980	-4,7062
Parapl.	VA25	DP30	SM32	
Step	-6,5244	-5,1520	-5,7172	
Ramp	-8,2781	-4,6118	-5,4880	

***Tab3**: Poles computed during the relaxation phase*

The gain is directly dependent on the frequency and the relation is reported in the following figures, that represent healthy and paraplegic subjects respectively, during the knee extension phase:

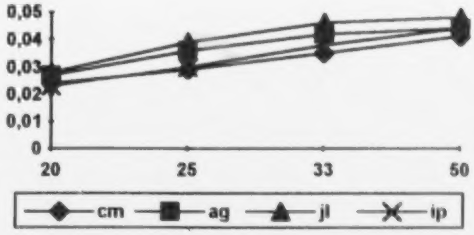


***Fig. 1**: Static gain at the various frequencies for healthy subjects, applying a step stimulus.*

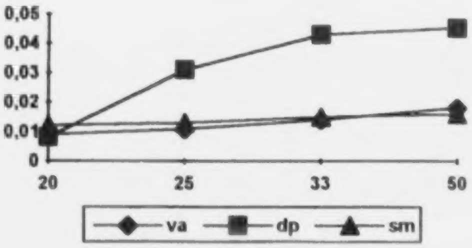


***Fig. 2**: Static gain at the various frequencies for paraplegic subjects, applying a ramp stimulus.*

In figure 3 the output of the first order model and the torque computed from real data (Me) for a step stimulus at the different poles frequencies on a healthy subject (IP26) are shown:

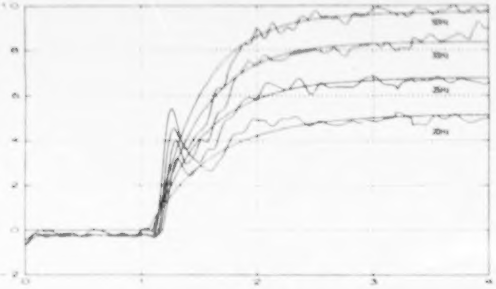


*Fig3: Simulated torque Me for a step stimulus at different pulse frequencies compared to real data; in the x axis is the time expressed in seconds, in the y axis is the knee torque expressed in N*m .*

In figure 4 the output of the first order model and the torque computed from real data (Me) for a ramp stimulus at the different poles frequencies on a healthy subject (IP26) are shown:

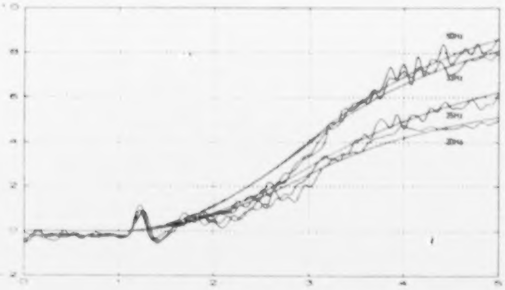


*Fig 4: simulated torque Me for a ramp stimulus at different pulse frequencies compared to real data; in the x axis is the time expressed in seconds, in the y axis is the knee torque expressed in N*m .*

CONCLUSIONS

Most of the previous studies on stimulus/force relationship were performed in isometric conditions [7] and/or considering in vitro experiments [8]: they are important for a basic knowledge of muscle characteristics. The presented approach allows to compute dynamically the joint torque produced by a stimulated muscle, providing the possibility to predict the effect of a particular stimulation pattern on joint movement. According to this possibility the transfer function between stimulation pattern and induced joint torque was identified in order to study pattern optimization and control scheme development for movement restoration in paraplegic patients. The experiment on paraplegics showed its applicability also on pathological subjects. Good results obtained encourage us to proceed in this approach.

REFERENCES

[1] Pedotti A, Ferrigno G. "*ELITE: a digital dedicated hardware system for movement analysis via real-time TV signal processing*". IEEE Transaction on Biomedical Engineering, 32: 943-949, 1985;

[2] Zatsiorsky V., Seluyanov V. "*The mass and inertia characteristic of the main segments of human body*". Biomechanics VIII-B, University Park Press: 1152-1159, 1983;

[3] Lin D. C., Rymer W. Z. "*A quantitative analysis of pendular motion of the lower leg in spastic human subjects*". IEEE Transaction on Biomedical Engineering, 38: 906-918, 1991;

[4] Ferrarin M., Baglioni P., Campisi A., Rabuffetti M., Pedotti A., "*Evaluation of the muscle torque at the knee joint resulting from electrical stimulation by using kinematic analysis*". Proc. of I EEC BIOMED RAFT workshop "Muscolar components in FES". June 25-26, 1993, pp.54-62, Salford, Inghilterra, 1993

[5] Philips G. "*Strathclyde Research Stimulator User Manual*", 1988;

[6] The Mathworks, inc. "*Matlab user's guide*", 1991;

[7] Levi M., Mizrahi J., Susak Z. "*Recruitment, force and fatigue characteristics of quadriceps muscles of paraplegics isometrically activated by surface functional electrical stimulation.*" Journal of Biomedical engineering, 12:150-156;

[8] Baratta R., Solomonow M. "*The dynamic response model of nine different skeletal muscles*". IEEE Transaction on Biomedical Engineering, 37: 243-251.

Maurizio Ferrarin
Centro di Bioingegneria, Fnd. Pro Juventute Don Gnocchi
Via Gozzadini 7
20148 Milano - Italy
(39) - 2 - 40308305

FNS ASSISTED STANDING PIVOT TRANSFERS FOR INDIVIDUALS WITH INCOMPLETE TETRAPLEGIA

R.J. Triolo, Ph.D.[1,2], E.B. Marsolais, MD, Ph.D.[1,2], G. Polando, M.S.[2], R. Kobetic, M.S[2]
1 - Department of Orthopaedics, Case Western Reserve University, Cleveland OH 44106
2 - Department of Veterans Affairs Medical Center, Cleveland OH 44106

ABSTRACT

Low cervical or high thoracic spinal cord injuries (SCI) often compromise the ability to transfer into or out of the wheelchair, thus limiting personal mobility and increasing the dependence on personal assistants. This study investigates the efficacy of an implanted functional neuromuscular stimulation (FNS) system to provide independent or facilitate assisted standing pivot transfer maneuvers. Four individuals with incomplete tetraplegia have participated in a staged program of exercise, standing transfer training and home trials of systems employing percutaneous intramuscular electrodes in preparation for the implanted FNS system. Three have been able to perform standing pivot transfers independently or with stand-by assistance outside of the laboratory, while the fourth is currently in the early stages of implementation and exercise. One subject has received an eight channel implant stimulator. Work is underway to provide the implantable system to the other subjects and to evaluate quantitatively its impact on their lives and those of their care-givers or personal assistants.

BACKGROUND

FNS has been used to provide standing, stepping and stair climbing to individuals with thoracic level SCI (1,2), or active grasp and release to those with cervical level lesions (2,3). However, more than 50% of all individuals with tetraplegia require assistance with activities of daily living involving community mobility or bed, chair, tub and toilet transfers (4). Almost two thirds of the population report needing assistance just to get into or out of the tub. This clinical need prompted researchers at Case Western Reserve University and the Cleveland VA Medical Center to investigate methods to provide the ability to perform independent standing transfers by stimulating the lower extremities of an individual with cervical level SCI in a single-subject case study (5). The current study extends this work and attempts to apply FNS to a group of individuals with a wide range of motor and sensory impairments and from a variety of personal and professional backgrounds.

Assisted transfers can also be facilitated by using FNS to raise, support, and lower the body, thus reducing the effort required by a care-giver. An FNS-assisted standing transfer system may decrease the need for heavy lifting on the part of family members, personal assistants, or other health-care providers, thereby reducing the risk of back injury both at home or in long-term care facilities.

Over 80 percent of people with SCI in nursing homes and institutions have tetraplegia, and incomplete injuries outnumber complete injuries by almost 2 to 1. Over two thirds of institutionalized persons with SCI report having little or no functional use of the muscles below the point injury, and persons with tetraplegia constitute the largest subgroup within this population (4). On the whole, institutionalized persons with SCI are more functionally dependent than their counterparts in the community. The dependence appears to result primarily from the impairment of motor function. FNS has the potential to address these motor deficits and may postpone or eliminate the need for institutionalization.

Stimulation can be delivered and controlled in various ways. Surface or percutaneous electrodes have been used in temporary systems employing external stimulators, but exhibit disadvantages stemming from issues related to donning/doffing, selectivity and reproducibility of responses, electrode movement and lead breakage, or skin condition at the electrode sites. These factors are minimized with implantable systems employing intramuscular, epimysial or nerve cuff electrodes. Multicenter clinical trials of an eight-channel implantable stimulator for hand grasp are currently underway (6,7).

PROBLEM STATEMENT

The purpose of this project is to design FNS systems and procedures for their implementation that will a) provide individuals with tetraplegia with the ability to perform standing pivot transfers independently, and b) facilitate assisted standing transfers for individuals with tetraplegia and their personal assistants. It is intended to test the hypothesis that a) selected individuals with low cervical SCI can be provided with the ability to perform a standing pivot transfer with an 8 channel percutaneous FNS system, and b) implantable 8 channel FNS systems for standing transfers are practical and safe for home use. Factor that may influence the design of systems and clinical procedures suitable for larger scale clinical trials are to be identified.

APPROACH

Temporary systems consisting of up to 12 percutaneous intramuscular electrodes are implanted in the hip, knee and trunk extensors (8). These electrodes are Teflon-insulated stranded stainless steel configured in open helical coils (i.e., "open helix" electrodes). The percutaneous systems are primarily for exercise and training in the operation of the custom multichannel stimulation devices (9). Subjects begin immediately with a program of exercise with FNS. When sufficient levels of strength and endurance are achieved, functional stimulation patterns are developed and standing activities are attempted.

Activation patterns are specified in an iterative process of trial and error. For assisted standing, the spotter stands close by user to guide and position the body after it is erect, rather than to lift the body as required in a standard pivot transfer. Standing can be initiated by the subject (or his/her assistant) by pressing a switch mounted on the external stimulator/controller. A delay between the switch depression and stimulation allows the user or assistant to reposition and prepare to stand. An audio tone signals the start of the stimulation sequence. In general, stimulation is delivered first to the quadriceps, followed by three of the following muscles: gluteus maximus, posterior portion of the adductor magnus, hamstrings or paraspinals. After repositioning for the transfer, another switch depression lowers the body to the seated position.

Each subject participates in up to three training or exercise sessions per week to refine the standing transfer maneuver and reduce the number of electrodes to eight. The temporary systems are then replaced by electrodes enclosed in a silicon sheath suitable for eventual use with an implantable stimulator (i.e., the "closed helix" configuration). Removable open helix percutaneous leads attached by subcutaneous in-line connectors mate with the external stimulator/controller for further system tuning, stabilization and initial trials in the community (10).

Once an optimal and stable eight channel system has been identified that provides safe and reliable standing transfers, the in-line connectors allow the percutaneous portion to be replaced by an implanted receiver/stimulator (11). All procedures, including introduction of the implantable receiver/stimulator, are performed on an out-patient basis. Follow-up by self report and regularly scheduled visits to the laboratory continue after discharge with the implanted system.

IMPLICATIONS

To date, four volunteers with incomplete tetraplegia have participated in the study. The clinical characteristics of each subject at entry into the program are presented below in Table I. All have been provided with FNS systems for exercise or functional use outside of the laboratory. The first three subjects were able to stand with FNS and have demonstrated the ability to perform a pivot transfer with minimal stand-by assistance. The fourth is in the initial stages of implantation and exercise.

Table I: Characteristics of Study Participants

				Extensor Manual Muscle Grade (0 to 5)			
Subj	Age (yrs)	SCI	Cause	Hip	Knee	Shoulder Elbow Wrist	Finger
LH	23	C6-7	MVA	L: 3 R: 0	L: 2 R: 0	L: 4,5,5 R: 4,5,5	L: 2 R: 2
RG	28	C7	MVA	L: 0 R: 0	L: 0 R: 0	L: 5,3,3 R: 5,3,3	L: 1 R: 1
DK	34	C5-6	MVA	L: 0 R: 0	L: 0 R: 0	L: 5,5,4 R: 5,5,4	L: 0 R: 0
ED	56	C7-T3	Fall	L: 0 R: 0	L: 0 R: 0	L: 5,5,5 R: 5,5,5	L: 4 R: 4

Note: MVA = "Motor Vehicle Accident"

The first subject has completed the course of testing and training and has received the implanted receiver/stimulator. The following two subjects are in the process of having their percutateous systems replaced with more robust "closed helix" electrodes in preparation for conversion to the implanted system. Table II summarizes the current status of each volunteer in the research program.

Table II: Current Status of Study Participants

	Phases of the Research Program					
	Stage I		Stage II		Stage III	
Subj	Open Helix	Exercise	Standing Pivot	Closed Helix	Implant Simulator	Home Use
LH	X	X	X	X	X	X
RG	X	X	X	\	-	-
DK	X	X	X	\	-	-
ED	X	\	-	-	-	-

X = Completed \ = In progress - = Planned

BEST COPY AVAILABLE

Conversion to implantable systems for the two experienced percutaneous users will continue, with implantation of the receiver/stimulator to follow shortly thereafter. For the most recent subject, exercise and initial standing/transfer training is scheduled to be completed within the next six months. Plans are currently being formulated to review of the technology and implementation-evaluation procedures in preparation for transfer to a clinical setting for larger scale trials.

Alternative command inputs have been devised to provide users with limited manual dexterity with the ability to operate the system independently. A portable folding walker that can be opened and closed without assistance has also been designed.

DISCUSSION

No technical problems have been encountered with the implanted receiver/stimulator; one electrode exhibited altered recruitment properties that did not adversely affect the performance of the transfer.

Users generally require assistance with donning/doffing the system. Although several subjects are able to exercise and stand independently, most rely on others to activate the stimulator and provide stand-by assistance. This suggests that the system may be better suited for facilitating an assisted transfer in this population. Few subjects appear able to assume or maintain a stable upright "C" posture due to activation of the rectus femoris or inadequate hip and trunk extension. This does not seem to compromise the ability to transfer, although it may affect the stability and independence of the maneuver.

The installation and optimization of two complete percutaneous systems prior to introduction of the implant stimulator/receiver currently consumes a great deal of time and resources. More efficient methods of implementing the system need to be investigated, such as prescribing an interval of surface stimulation to hypertrophy the muscle prior to electrode implantation. The external control unit, cabling, controls and clinical interface for specifying stimulation parameters also need to be re-evaluated in terms of reliability, manufacturability, and ease of use. New versions of these components will have to be designed and produced before more extensive clinical trials can proceed.

REFERENCES

1. E.B. Marsolais, et al. "Functional electrical stimulation for walking in paraplegia," *JBJS* 1987: 69A:728-33.
2. P.H. Peckham "Functional electrical stimulation: current status and future prospects of applications to the neuromuscular system in spinal cord injury," *Paraplegia* 1987, 25:279-85.
3. P. Gorman, et al. "Upper extremity functional neuromuscular stimulation," *J Neuro Rehab* 1991; 5:3-11.
4. Berkowitz, et al. Economic Consequences of Traumatic SCI. Paralyzed Veterans of America, Demos Publications NY, 1992, pg. 90-2.
5. E.B. Marsolais, et al. "Augmentation of transfers for a quadriplegic patient using an implanted FNS system. Case report," *Paraplegia* 1994, 32:573-9
6. M.W. Keith, et al. "Implantable functional neuromuscular stimulation of the tetraplegic hand," *J Hand Surg* 1989, 3:524-30.
7. K.A. Kilgore, et al. "An implanted upper extremity neuroprosthesis," *Proc 16th RESNA*, Las Vegas, NV 1993, 404-6.
8. E.B. Marsolais et al. "Implantation techniques and experience with percutaneous intramuscular electrodes in the lower extremities," *J Rehab Res Dev* 1986, 23(3):1-8.
9. G. Borges et al. "Development and operation of portable and laboratory electrical stimulation systems for walking in paraplegic subjects," *IEEE Trans Biomed Engr* 1989, 36(7):798-800.
10. A. Scheiner, et al. "Design and Clinical Application of a Double Helix Electrode for Functional Electrical Stimulation," *IEEE Trans Biomed. Engr* 1994, 41(5):425-31.
11. B. Smith, et al. "An externally powered, multichannel implantable stimulator for versatile control of paralyzed muscle," *IEEE Trans Biomed Engr* 1987, 34(7):499-508.

ACKNOWLEDGMENTS

This work was supported by Grant #B743-RA from the Department of Veterans Affairs, Research and Development Service, Washington DC. The authors also extend special thanks to the individuals who volunteer to participate in this study, as well as to their families and friends for their assistance.

Ronald J. Triolo, Ph.D.
Motion Study Lab 151 A(W)
VA Medical Center
10701 East Boulevard
Cleveland, OH 44106

ELECTRICAL STIMULATION IN THE MANAGEMENT OF MUSCLE DISUSE OR TEMPORARY MUSCLE DENERVATION CAN BE EFFECTIVE AND COMFORTABLE

Joyce M. Campbell, Paul M. Meadows
Department of Physical Therapy, Cal State University Long Beach, CA, USA
Rancho Rehabilitation Engineering Program, Downey, CA, USA

ABSTRACT

The use of electrical stimulation [ES] in rehabilitation of both innervated and denervated muscle has been discarded by some therapists because of patient discomfort and non-compliance. A major problem is the lack of understanding of how to accomplish treatment objectives without pain. The purpose of this paper is to review commonly overlooked principles of therapeutic stimulation for denervated as well as innervated muscle and to present the results of a study in which minimal, comfortable ES improved quadriceps muscle performance (work performed [W] and fatigue resistance [FR]) significantly more than the use of EMG feedback (p<.0001) in 39 healthy individuals. The characteristics of the first recruited quadriceps motor units were related to voluntary performance and the improvement in W and FR when ES was added to knee extension exercise. Individuals who recruited larger motor units early demonstrated the greatest improvements in W and FR during ES.

BACKGROUND

Although patients with muscle weakness secondary to disuse and patients with temporary but complete loss of motor innervation have different short-term goals, they have a mutual interest in remaining comfortable during the application of therapeutic electrical stimulation [ES]. The selection of an appropriate stimulus is critical to the success of any clinical or home ES program. This is often overlooked by engineers, manufacturers and clinicians.

The changes in muscle after loss of peripheral nerve supply are profound and axonal regrowth may continue for months to years before it can reinnervate all of the key muscles for function [1]. In the absence of volitional control, ES is the only tool available to keep the intramuscular connective tissue mobile so that the muscle will be able to become useful once nerve supply has been restored [2]. Simple joint range of motion will not generate three dimensional movement within the denervated muscles. For many decades, clinicians have prescribed ES to help maintain denervated muscles until reinnervation occurs, but the majority of patients have not been able to tolerate the pain. Galvanic current has been the most popular (and the most painful) [3]. Galvanic is unidirectional, likely to irritate the skin, and more important it is excessively long in duration (> 300 mS). The majority of patients with muscle denervation still have sensation in the skin overlying the paralyzed muscle and they cannot tolerate enough stimulus intensity to activate the denervated muscle. A classic example is the patient with facial nerve damage whose trigeminal nerve still innervates the skin over the face.

It is possible to move, or contract, the denervated muscles with a much shorter, more tolerable waveform. A standard electrodiagnostic test, the Strength-Duration Curve, permits visualization of a pulse duration that will effectively activate the denervated muscle with minimal or no discomfort [4] (Fig 1). Selection of a pulse duration just above Chronaxie (ie 5-7 mS in this example) assures a muscle response with a minimum of sensory irritation. As stimulus amplitude is increased to produce three dimensional movement in the muscle, the patient is extremely comfortable in comparison to the use of Galvanic current.

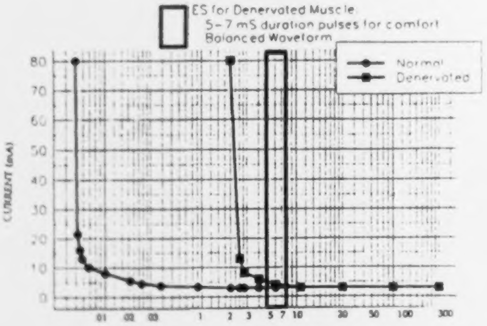


Fig. 1. Strength-Duration Curve for normal and completely denervated muscle. Rheobase = 4 mA, Chronaxie (Normal) = <1.0 mS, Chronaxie (Denervated) = 4 mS. A pulse duration between 5 and 7 mS offers optimal muscle activation and comfort for this denervated muscle.

BEST COPY AVAILABLE

Selection of the most comfortable stimulus characteristics and ES protocol are equally critical to the management of muscle weakness secondary to immobilization, trauma, residual weakness after peripheral nerve reinnervation, traumatic brain injury or stroke. Comfortable stimuli (ie balanced 300 uS pulses) [5] have been used to provide sensory cues, elicit functional reflexes and manage spasticity in patients with central nervous system pathology. The majority of ES applications for the patient with disuse weakness, however, have focused on maximal tolerable ES and the measurement of muscle force production as the criterion for success. Most patients will not tolerate enough stimulus intensity to generate forceful movement against gravity and prefer not to use high stimulus levels during exercise. Assessment of the work performed and the fatigue resistance during an exercise protocol have been largely ignored despite the clinical relevance of these measures. Maximal tolerable ES superimposed upon volitional effort did not prove to be more effective in changing muscle performance than minimal, comfortable ES in a recent report on 20 normal subjects [6].

In a study of healthy subjects, we proposed to detect differences in knee extension [KE] muscle performance (peak moment [PM], work performed [W] and fatigue resistance [FR]) between maximal volitional exercise [VOL] (60 deg/S), and the same exercise with superimposed ES [VOL+ES] or visual electromyographic feedback [VOL+EMGFB]. Characteristics of the first requited motor units [MU] were compared with exercise performance.

METHODS

Subjects: 39 normal subjects (28.0 ±4.8 years) participated. None of the subjects used ES for regular exercise.

Instrumentation: Cutaneous electrodes (3x4 inch, PALSFLEX, Axelgaard Mfg, Fallbrook, CA) were used for open loop ES exercise (asymmetrical biphasic, 300 uS, 33 pps). ES was provided by a modular stimulator, plug-in board in an IBM PC/AT. KE exercise was controlled a the LidoActive dynamometer (Loredan Biomedical, Davis, CA). Analog signals from the LidoActive system were sampled by the IBM for angular position, velocity and moment. A second IBM system sampled the integrated EMG signal (skin electrodes) and displayed a dynamic vertical bar with a target level based upon the subject's maximum IEMG. Calibration, gravity compensation and all data acquisition were performed by the IBM system. An auditory beep (headphones) cued the subject to perform the next KE in voluntary trials, and the onset of ES cued the subject in VOL+ES KE. The electrical stimulator was programmed to allow the limb to return to 80 degrees of flexion and then immediately stimulate again. No rest interval was allowed between repetitions in either mode of exercise. Disposable monopolar needle electrodes were used for MU assessment (Cadwell 5200A, Cadwell Laboratories, Kennewick, WA).

Procedure: During each exercise session, a 40 repetition, maximal KE protocol was performed. VOL was performed first and the order of subsequent trials varied. Subjects were not permitted to use their upper limbs to assist. A recruitment curve was performed immediately prior to the VOL+ES trial. The current intensity at which the subject first noted stimulation was recorded as their threshold, and the minimal level of ES used for testing was the intensity (mA) required to produce 1-2 Nm of KE moment (ie 1-2 Nm compared to a range of 100-300 Nm VOL KE). Peak moment and work performed were documented for each KE repetition and performance data were plotted by a custom software protocol. Each subjects maximum effort was accepted as MVC based upon previous documentation of the repeatability of isokinetic fatigue curves [7]. A high intensity burst of ES was not employed to assess recruitment because of the discomfort involved and the potential influence on subject compliance and performance in the ensuing data collection periods [8]. The amplitude and firing rate of the first recruited motor units in the vastus lateralis and medialis were recorded during a separate visit to the laboratory.

RESULTS

VOL+ES resulted in larger peak KE moments in some subjects, but only VOL+EMGFB resulted in statistically greater KE moment (Table). ES improved KE W and FR over the 40 repetition test (p<.0001, p<.01). None of the subjects were uncomfortable during VOL+ES exercise. W and FR were not altered by the addition of EMG feedback. A statistical trend indicated that subjects with larger early MU (during minimal effort) demonstrated the greatest improvements in FR and in W during VOL+ES when they were compared to subjects with smaller initial motor units.

Table. KE muscle performance during 40 repetition exercise test (60 deg/S). The addition of 1-2 Nm of ES muscle contraction improved W and FR over voluntary and EMG feedback trials. (Repeated measures ANOVA, Bonferonni.)

	VOL	VOL+ES	VOL+EMGFB	SUMMARY *p<.01, **p<.0001
Peak KE Moment (Nm)	181.6 ±54.5	180.1 ±50.1	191.1 * ±52.7	VOL+EMGFB > VOL & VOL+ES
% Decrease in KE Moment (40 reps)	43.8 ±11.2	39.3 * ±11.4	46.3 ±9.6	VOL+ES > VOL & VOL+EMGFB
Work (Nm-deg) 40 reps	3907 ±1222	4921 ** ±1327	4058 ±1162	VOL+ES > VOL & VOL+EMGFB
Work (Nm-deg) on Peak KE rep	133.8 ±44.1	159.1 ** ±45.7	138.9 ±39.2	VOL+ES > VOL & VOL+EMGFB
% Decrease in Work (40 reps)	41.8 ±12.9	38.1 * ±12.2	43.5 ±12.3	VOL+ES < VOL & VOL+EMGFB

CONCLUSION

The addition of a minimal electrically stimulated muscle contraction (1-2% of maximal voluntary effort) to KE exercise significantly improved work performance and fatigue resistance during exercise. The addition of EMG feedback improved peak torque, but fatigue and work were not significantly altered. The relationship between early recruited motor units and the shift in performance during VOL+ES may point to an underlying neurological mechanism. Contrary to previous suggestions [9], those subjects with larger initial MU improved the most in W and FR with minimal ES, while their KE peak moment remained the same or decreased slightly. If ES of superficial, large motor axons differentially inhibited volitional motor unit firing, it could result in a greater reliance upon smaller, more fatigue resistant MU in the quadriceps [10]. Muscle performance and function can be significantly improved by ES in both disuse and denervation, but it is not necessary to torture patients with excessive amounts of ES. Comfort is the "bottom-line" to patient compliance and successful outcomes.

REFERENCES

1. Gelberman RH: Operative Nerve Repair [1-2]. Philadelphia, JB Lippincott, 1991.
2. Thomson JD: Effect of Electrotherapy on Some Mechanical Properties of Denervated Muscle. Am J Phys Med 36:16-20, 1957.
3. Robinson AJ, Snyder-Mackler LS:Clinical Electrophysiology. Baltimore, Williams & Wilkins, 1995, pp196-199.
4. Sunderland SS: Nerves & Nerve Injuries. Edinburgh, C. Livingstone, pp257-263, 1978.
5. Bowman BR, Baker LL: Effects of waveform parameters on comfort during transcutaneous NMES. Ann Biomed Eng 13:59-74, 1985.
6. Campbell J, Meadows P, Talbot A, Jones A, Ford H, Stefan M: Volitional Exercise plus ES: Significantly Improved Muscle Performance. Proc RESNA, Nashville TN, June 1994, pp370-372.
7. Carter CL, Campbell JM, Anderson B, Tufenkian EL: Reproducibility of Isokinetic Fatigue Curves. Phys Ther 67:757, 1987.
8. Binder-Macleod SA, Barrish WJ: Force Response of Rat Soleus Muscle to Variable-Frequency Train Stimulation. J Neurophysiol 1068-1078, 1992.
9. Delitto A, Snyder-Mackler L: Two theories of muscle strength augmentation using percutaneous ES. Phys Ther 70:158-164, 1990.
10. Henneman E: Recruitment of Motoneurons. In: Desmedt JE [Ed]:Motor Unit Types, Recruitment and Plasticity in Health and Disease. Progress in Neurophysiology 9:26-60, 1981.

Acknowledgments: J Bryan, S Guyton, N Lopez, C Parker, A Hebert, S Hunsaker, J Kaplan.

Joyce Campbell, Ph.D., P.T., Physical Therapy
California State University, Long Beach
1250 Bellflower Boulevard, ET-130
Long Beach, CA 90840-5603, USA
(310) 985-5455

ELECTRICALLY-INDUCED CONTRACTIONS VS EXTERNAL COMPRESSION FOR PROMOTING VENOUS RETURN DURING HIP AND KNEE SURGERY

Hjalmar F. Pompe Van Meerdervoort, Sahar Hassani, Pouran D. Faghri, and Roger M. Glaser
Institute for Rehabilitation Research and Medicine, Wright State University School of Medicine; and Rehabilitation Institute of Ohio, Miami Valley Hospital, Dayton, Ohio, USA

ABSTRACT

The purpose of this study was to compare venous return in patients undergoing total hip and knee replacement surgery using the sequential compression device (SCD) which externally squeezes the calf and thighs in a rhythmic pattern, and rhythmic electrical stimulation (ES)-induced contractions of calf and thigh muscles to directly activate the skeletal muscle pump. For this, 11 subjects received SCD, whereas 11 subjects received ES. At 15 min intervals, venous return was monitored indirectly by determining ventricular stroke volume (SV) and cardiac output (CO) via non-invasive impedance cardiography. In comparison to SCD, it was found that SV averaged 34% higher ($p < 0.05$) and CO averaged 19% higher during ES. Heart rate was consistently lower during ES (-27%), whereas mean arterial blood pressure was similar for both groups. These data suggest that the ES technique may offer greater deep venous thrombosis and pulmonary embolism protection in a more physiologic manner than the widely used SCD.

INTRODUCTION

In surgical patients, anesthesia and subsequent bed rest contribute to the loss of the skeletal muscle pump, resulting in reduced venous return of blood from the lower extremities. During total hip and knee replacement surgery, blood stasis, damage to the intimal lining of the vessel, and hypercoagulability are major factors contributing to the development of deep venous thrombosis (DVT). Indeed, the incidence of DVT in patients with total hip and knee replacement has been reported to range from 20% to 70%, with further complications of pulmonary embolism (PE) from 4.6 % to 20%, resulting in a mortality rate of 2-3% (1-4). Therefore, it is imperative to study techniques to improve lower-limb blood flow during hip and knee surgery to prevent DVT and PE.

Medications (i.e. heparin, coumadin) and physical methods (i.e., external compression) to enhance blood flow are commonly used prophylactic treatments that can reduce coagulability of the blood (1,4,5). During and following hip and knee surgery, a widely used mechanical method is a sequential compression device (SCD). This device operates by rhythmically compressing the calf and thigh muscles. However, SCD is unable to produce the contractions required to activate the skeletal muscle pump. Thus, it can not completely empty the veins, and it allows for continued venous stasis (4,5). In contrast, rhythmic electrical stimulation (ES)-induced contractions of the calf and thigh muscles directly activate the skeletal muscle pump to better alleviate venous stasis. In geriatric and mobility impaired patients, application of rhythmic ES on the thigh and calf muscles was found to be effective in reducing venous stasis as indicated by increased cardiac output and ventricular stroke volume (6,7). Therefore, the purpose of this study was to compare venous return in patients undergoing total hip and knee replacement surgery using the SCD and ES techniques.

METHODS

Eleven subjects (8F, 3M, mean (± SD) age=67.3 ± 8.9) received SCD, whereas eleven subjects (5F, 6M, mean age=65.1 ± 9.3) received ES. Both the SCD and ES groups received prophylactic medication prior to surgery. All volunteers for this study were medically screened and signed the IRB-approved consent form prior to testing.

For total hip surgery, SCD or ES was applied to the calf (tibialis anterior and gastrocnemius-soleus) and thigh (quadriceps and hamstrings) of the non-operative leg and only the calf of the operative leg. For total knee surgery, only the non-operative leg received the SCD or ES treatment. For ES, an eight-channel stimulator was used to induce pulsatile isometric contractions. Rubberized carbon skin surface electrodes were placed over motor points of the muscles, and ES intensity was set to provide the strongest contractions obtainable without discomfort. ES consisted of rectangular pulses that were 0.3 msec in duration, at a frequency of 35 Hz. Stimulator output current was limited to 65 mA. SCD utilized a vinyl plastic sleeve placed over the leg with individual compartments that inflated from the calf to the thigh. SCD and ES used the same timing pattern with a total of 11 sec of application (4 sec of calf followed by 7 sec of calf and thigh) followed by 60 sec of rest. This cycle of 11 sec of application and 60 sec of rest ran through the duration of the surgery (60-75 min).

Venous return was monitored indirectly by determining ventricular stroke volume (SV) and cardiac output (CO) via non-invasive impedance cardiography. Aluminized band electrodes were placed on the foot, forehead, neck, and thorax to monitor changes in impedance and to calculate the central hemodynamic responses of SV, CO, and heart rate (HR). "ASYST" software in conjunction with an IBM portable 386 type computer was used to collect the impedance data, as well as to provide data analysis. Impedance data were collected at the start of surgery, every 15 min during surgery, end of surgery, and 5 min post surgery. Mean arterial pressure (MAP) was monitored by auscultation. Data were statistically analyzed by using one-way analysis of variance. Significant differences were accepted at the 0.05 level.

RESULTS

Subjects did not report any problems for using the SCD or ES methods during surgery. Figures 1-4 provide comparison data for using the SCD or ES. Throughout the duration of SCD or ES application, patients who received ES had a significantly higher SV, averaging 34% higher (p<.05), than those receiving SCD (Fig. 1). Unlike SCD, ES was able to maintain SV above baseline during the entire operation. Similarly, the average CO was found to be 19% higher during ES use than with SCD, and the CO was maintained above baseline (Fig 2). In contrast, HR was consistently lower during ES than SCD averaging -27% (Fig. 3). There was no apparent difference between the SCD and ES groups regarding MAP (Fig 4).

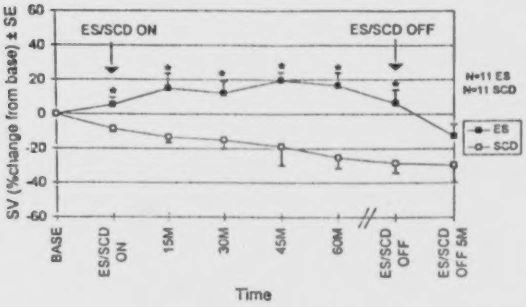


Figure 1. Percent change from baseline for stroke (SV) volume when using the SCD and ES methods.
* indicates significance at the 0.05 level.

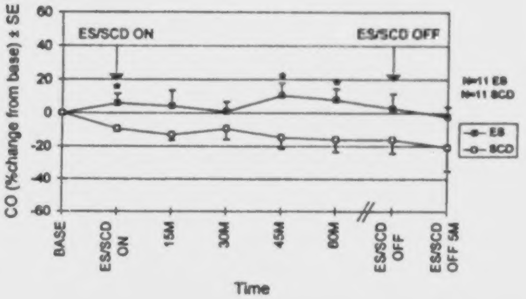


Figure 2. Percent change from baseline for cardiac output (CO) when using the SCD and ES methods.
* indicates significance at the 0.05 level.

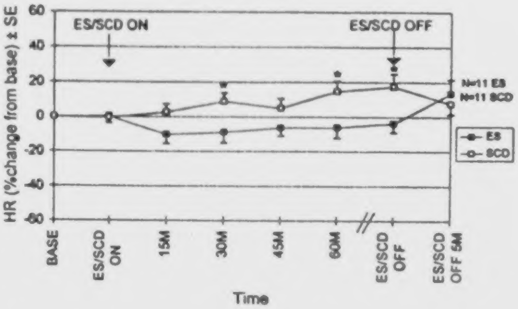


Figure 3. Percent change from baseline for heart rate (HR) when using the SCD and ES methods.
* indicates significance at the 0.05 level.

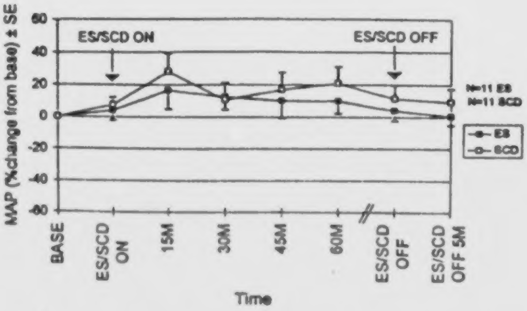


Figure 4. Percent change from baseline for mean arterial pressure (MAP) when using the SCD and ES methods. No significant differences were found.

DISCUSSION

The use of rhythmic ES-induced lower-limb contractions has been found to significantly enhance venous return, SV and CO in able-bodied, spinal cord injured and geriatric individuals (6,7). It is apparent that these contractions directly activate the skeletal muscle pump as opposed to the SCD which

BEST COPY AVAILABLE

merely exerts external compression upon the limbs. Glaser, *et al.* (7) found that it was necessary to contract both the calf and thigh muscles to promote venous return, and that activating only the calf or thigh muscles did not have a marked circulatory effect. However, most previous DVT prophylactic studies incorporating ES-induced contractions utilized only the calf muscles (8-10). For this study, we used the same 11 second timing cycle for the SCD and ES mode. This is in contrast to the shorter timing cycles that were previously reported for ES (e.g., 1.5 to 2.5 sec on and 1.5 to 2.5 sec off) (6,7).

It has been found that blood flow velocity in the lower limbs can be markedly reduced while under general anesthesia (8). This could increase its coagulability. Thus, if the ES-induced contractions could effectively promote greater lower-limb blood flow and reduce venous stasis during surgery, this could possibly prevent the genesis of DVT. In the present study, the use of ES during total hip and knee replacement surgery was found to elicit a higher SV and CO than using the SCD. During the intraoperative period, only ES was able to maintain SV and CO above the initial non-SCD/ES baseline readings. These results demonstrated the ability of ES to activate the skeletal muscle pump to promote venous return while under anesthesia. Furthermore, patients receiving ES maintained HR below the initial non-SCD/ES baseline reading. This suggests that the volume loading of the heart (i.e., Frank-Starling mechanism) which increased SV and CO stimulated reflexes to reduce HR (e.g., baroreceptor reflex). There were no clear differences in MAP for the methods tested. This suggests that the total peripheral resistance for the ES mode was lower which may have further facilitated lower-limb circulation.

From these results, it appears the described ES technique can provide a more physiologic manner in the prevention of venous stasis during surgery. This may offer greater DVT and PE protection than the commonly used SCD. However, research that directly examines the incidence of DVT for using the SCD and ES techniques is needed to establish efficacy.

REFERENCES

1. Borow, M., Goldson, H. Postoperative Venous Thrombosis. *The American Journal of Surgery*, 141:245-251, 1981.

2. Hull, R.D., Raskob,G.E. Prophylaxis of Venous Throboembolic Disease Following Hip and Knee Surgery. *The Journal of Bone and Joint Surgery*, 68:146-150,1986.

3. Swayze, O.S., Nasser, S., Roberson, J. Deep Venous Thrombosis in Total Hip Arthroplasty . *The Orthopedic Clinics of North America* 23:359-364, 1992.

4. Woolson, S., Watt, J.M. Intermittent Pneumatic Compression to Prevent Proximal Deep Venous Thrombosis During and After Total Hip Replacement. *The Journal of Bone and Joint Surgery*, 73:507-512, 1991.

5. Hull, R.D., Raskob, G.E., Hirsh, J. Prophylaxis of Venous Thromboembolism. *Chest*, 89:374S-383S, 1986.

6. Figoni, S.F., Glaser, R.M., Suryaprasad, A.G., Gupta, S.C. Cardiovascular Responses of Geriatric Men to Electrically Stimulated and Voluntary Leg Muscle Contractions. *Proc. 16th RESNA Conf. Rehabil. Technol.* pp. 392-394, 1993.

7. Glaser, R.M., Rattan, S.N., Davis, G.M., Servedio, F.J., Figoni, S.F., Gupta, S.C., Suryaprasad, A.G. Central Hemodynamic Responses to Lower-Limb FNS. *IEEE/Ninth Annual Conference of the Engineering in Medicine and Biology Society*, 0615-0617, 1987.

8. Doran, F.S.A., Drury, M., Sivyer, A. A Simple Way to Combat the Venous Stasis Which Occurs in the Lower Limbs During Surgical Operations. *Brit. J. Surg.* 51:486-492, 1964.

9. Doran, F.S.A., White, H.M. A Demonstration that the Risk of Postoperative Deep Vein Thrombosis is Reduced by Stimulating the Calf Muscles Electrically During Operation. *Brit. J. Surg.*, 54:686-689, 1967.

10. Rosenberg, I.L., Evans, M.., Pollock, A..V. Prophylaxis of Postoperative Leg Vein Thrombosis by Low Dose Subcutaneous Heparin or Preoperative Calf Muscle Stimulation : A Controlled Trial. *Brit. Med. J.* 1:649-651,1975.

Acknowledgment. This study was supported by the Pruett foundation for Geriatric Research.

Hjalmar F. Pompe Van Meerdervoort, M.D., Chair
Department of Orthopaedic Surgery
Wright State University School of Medicine
Dayton, Ohio 45435 U.S.A.
(513) 220-2091

SIG-11
Computer Applications

ADAPTING SPEECH INPUT COMPUTING FOR INDIVIDUALS WITH SPEECH IMPAIRMENTS

Douglas R. Bowes
Special Education Technology -British Columbia
Victoria, British Columbia, Canada

ABSTRACT

A variety of voice data entry computers are now in use in business and education. They are sold by a number of companies and go by the names that include IBM VoiceType, Dragon Dictate, Kurzweil Voice and others. Originally these devices were marketed for able-bodied computer users but soon the advantages for individuals who cannot use a regular keyboard brought these devices into wider use. Individuals with speech impairments have greater difficulties using this technology and may require adaptations to software, hardware, positioning, therapies and training regimes. This session will examine some of the strategies used in The Voice Project to adapt IBM VoiceType Computers for students with speech impairments as well as ways that voice input computing may be used as an adjunct to speech therapy. While VoiceType is the product examined here, there is enough similarity among other products to generalize some of the approaches outlined here to other voice data entry systems.

BACKGROUND

The Voice Project is a cooperative project among British Columbia schools and students, IBM Canada and Special Education Technology-British Columbia (SET-BC). Seven IBM Computers equipped with VoiceType speech input software and IBM M-ACPA (monaural-audio capture and playback adaptor) cards were used with seven students who could not effectively use a computer keyboard and had significant speech difficulties were nominated by their home school districts. The participants were representative of all regions of British Columbia.

The Goals of the Voice Project:

1) To allow the student participants to produce their written communication and written school work independently ,

2) To make the necessary adaptations to software, hardware and training methods so that students with specific disabilities could use this technology effectively, and

3) To examine if any improvements in oral communication (speech) occurred as a result of using VoiceType.

OBJECTIVE

To demonstrate how to adapt speech input computers such as VoiceType for users with various speech difficulties. As well this session will discuss how speech input computing can be used as an adjunct to speech therapy.

APPROACH

The seven students in this project have a variety of disabling conditions including cerebral palsy, muscular dystrophy, and others and come from elementary and Junior High Schools across the province. All of the participating students have great difficulty producing their written work without assistance, and most have significant speech difficulties that effect intelligibility.

Initial training occurred in the individual students' home during their summer vacation with follow up training occurring during the fall and winter sessions . During the first sessions, almost all of the students failed to achieve even minimal success using VoiceType. All of the students training programs were modified using one or a number of the following approaches:

1) Modify VoiceType Command training. The recommended training procedure has the user train over two hundred VoiceType Commands before they can begin to use VoiceType. The students often lacked the stamina to effectively complete the recommended individual training modules. A modified procedure was introduced that reduces the number of commands trained the frequency of the sample and the amount of training time necessary to be able to effectively use VoiceType.

2) Modify software parameters. VoiceType software allows the user to adjust parameters so that individual speech patterns can be recognized and interpreted by the computer. The most significant of these are rejection

threshold and word pause. The former can be adjusted to allow for greater variation in the repeated production of words. This session will demonstrate how to make these modifications and how they can be used to assist the user with speech impairments.

3) Modify breathing patterns for more efficient speech production. For users who lack the vocal intensity to activate the VoiceType interface because of inefficient breathing patterns modified training is indicated. A shoulder clavicular breather lacked the stamina and vocal intensity to activate the VoiceType system. Initial training could not take place until this student was lying in bed and given instructions on the more powerful diaphragmatic method of breathing. Seating was adjusted to promote diaphragmatic breathing and the user was able to effectively input speech into the computer.

4) Line amplifier: An amplifier can be placed on line between the microphone and the M-ACPA card to increase the signal input to the computer from the low speech intensity user.

5) Modify user input. Multisyllabic words presented difficulties for some users with motor speech problems. VoiceType commands such as "begin spell mode" and words of three or more syllables were often distorted because of varied prolongations, extended transitions and excessive emphasis on certain syllables. The modified VoiceType command "Spellit" could be used to bring up the "begin spell mode" command. To enter "geography" into a word processing document a user might try saying "jogfree" and so on.

RESULTS

All of the students increased their ability to produce written work significantly. Most of the students tripled their WPM output with one improving by 25%. Other benefits included increased speech intelligibility and endurance (see figure 1 and figure 2) .

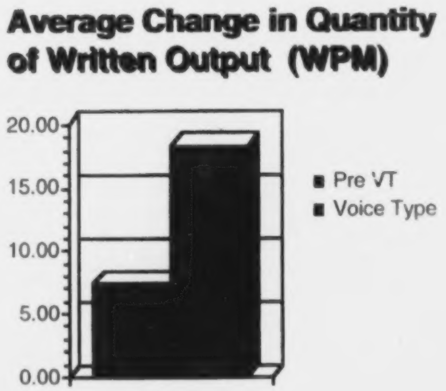


Figure 1

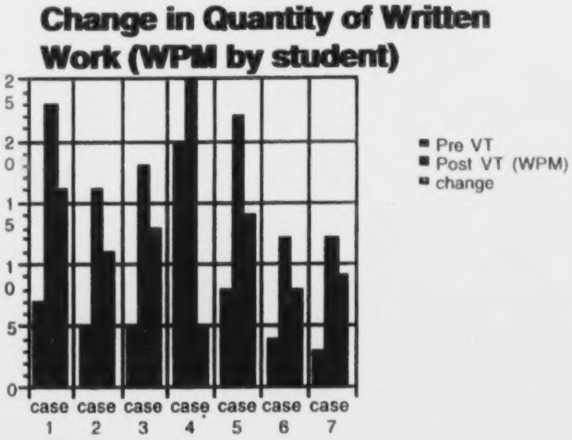


Figure 2

In addition to increased written output some of the students received ancillary benefits to speech and language programs. As indicated above, one user had to modify his breathing patterns in order to achieve the vocal intensity required to activate the VoiceType interface. The use of VoiceType, therefore, became a carryover activity for speech therapy. Whenever the Computer didn't respond to his voice he would modify his posture and breathing patterns until he achieved the vocal intensity required to activate VoiceType. VoiceType would provide immediate and accurate feedback on breathing and posture.

Some of the VoiceType users demonstrated increased stamina and endurance in speaking while using VoiceType. It was felt this may be a result of the discipline and speech patterns that VoiceType users must maintain in order to use the product effectively.

Other areas not fully explored include VoiceType as an adjunct to speech therapy, growth in sight vocabulary among VoiceType users and changes in self concept as a result of being able to produce a significant amount of their written work independently.

ACKNOWLEDGEMENT

Funding for the specialized equipment was provided by the Woodward foundation. IBM Canada provided technical and equipment support, SET-BC provided equipment, technical administrative and travel support and a speech therapist/technology consultant for research design and student training/support.

Special thanks to Pat Stoddart of IBM (presently at the Hugh MacMillan Centre) and John Drescher of SET-BC central office.

Doug Bowes
Speech Language Pathologist
Consultant Special Needs Technology
SET-BC
2260 Victor Street, Victoria, B.C. , Canada V8R 4C5
(604) 595-7511 Fax (604)595-7224

GRIPPY MOUTHSTICK FOR MANAGING FLOPPY DISKS AND COMPACT DISKS

Nicole E. Hawkins and J. Riley Hawkins, CO
Center for Rehabilitation Technology
Georgia Institute of Technology

Abstract

Computers are a valuable resource and have become a common tool. Persons with disabilities who use computers are able to achieve many of their goals in areas such as education and employment. A common problem with using a computer is the management of floppy disks and more currently compact disks. Persons who use a mouthstick for typing, or any input device other than touch typing may have difficulty with the insertion and removal of their floppy disks. The Center for Rehabilitation Technology developed a mouthstick specifically for this purpose.

Background

The project began when a college student requested if there was a way he could use his floppy disks without relying on an individual to insert and remove the disks from his computer. This specific problem did not seem like a new problem and we thought a device to help our client manage his disks should exist in the market place. An information search was done by CRT's TechKnowlege Department and a mouthstick was found which had a moveable tip for grabbing objects. The tip is tongue actuated by a button located in the fork of the mouthpiece, a rubber band is used to supply clamping force. The major problem we found with this type of gripping mouthstick was the orientation of the tip. The tip was positioned at a 90° angle from the shaft, which meant the orientation of the computer set up would need to be at the same angle. Also, the rubber band wasn't strong enough to hold the weight of a disk. We decided to create our own mouthstick specifically designed for the management of floppy disks.

We also searched for disk holders which provided easy access to the disks but existing ones stored the disks too close together. So, we also decided to design a new disk holder to aid in the disk management process.

Objective

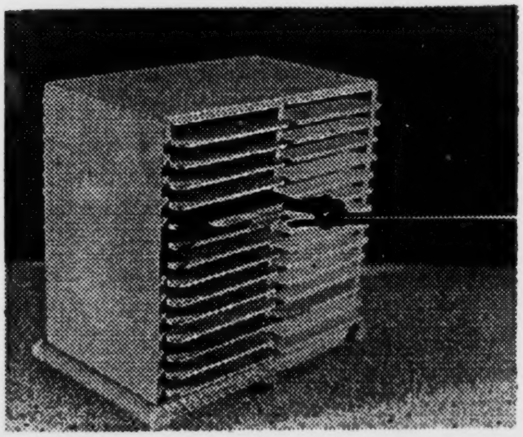
The new device needed to offer a definitive answer for the management of computer software by allowing a person to use a mouthstick to handle their disks. The mouthstick needed to be mechanically operated using the tongue and strong enough to hold the weight of a floppy disk or compact disk. The design also needed to include a storage bin in which the disks could be accessed with a pincer tip.

Approach

We needed a design which would give us the same result as the rubber band technology but stronger and more reliable. The design we chose incorporated a plastic cable push rod and an o-ring belt compression spring. So, the tongue pushes a button connected to the rod causing the pincers to open and the belt closes the pincers once the tongue releases the rod. This design allows the mouthstick to hold the disk after it is retrieved not requiring the tongue to hold it in position.

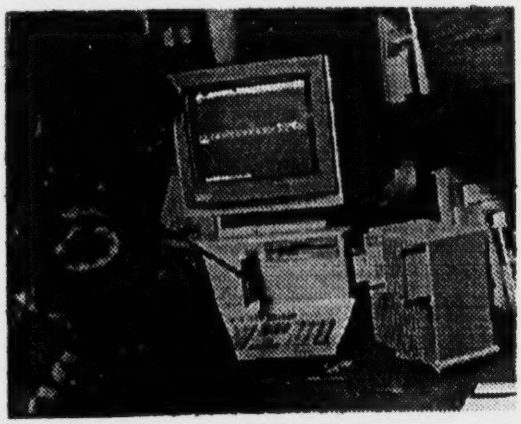
The pincers were machined from plastic and operate in a jaw like movement around a pivot point. We used thin wall aluminum tubing because of the materials strength, price and color selection. The mouth piece is an existing product available through Independence Technologies. It is a formable mouthpiece which is heated and placed in the mouth to make an impression. This helps the mouthstick stay in place at the same time distributing pressure.

The floppy disk holder was designed to hold 60 disks in either a vertical or horizontal position depending on the orientation of your disk drive. It holds 30 disks per side and rotates within a 5" radius. The disks protrude from the storage compartment and the spacing for each disk is appropriate for the Grippy to grab the disk on both sides. These design elements create a compatible means of disk management.



Discussion

We have had great response towards the Grippy Mouthstick. The college student who received the first prototype has had great success and enjoys the freedom of working at his computer without help. We have since discovered several people who experience this same problem and are in the process of delivering more Grippy Mouthsticks. Our future plans are to go to a different manufacturing process by molding the pincers in an effort to reduce the cost of fabricating the product. The fabrication costs now are $550.00. The Grippy Mouthstick can be purchased through the Center for Rehabilitation Technology at 1-800-726-9119.



Acknowledgements

This project was funded through the Center for Rehabilitation Technology and the Georgia Department of Rehabilitation Services for an individual in the Technology Access Program.

Nicole E. Hawkins
Research Scientist
J. Riley Hawkins, CO
Research Engineer
Center for Rehabilitation Technology
Georgia Institute of Technology
Atlanta, GA 30332-0156

Using an Extensive Abbreviation System to make Augmentative Speech an Effective Reality

Geri Esten

Abstract

Spelling based augmentative communication systems allow individuals to communicate unique thought and ideas, but letter by letter spelling is often so slow that technology designed for this purpose goes unused.

Abbreviation expansion can decrease the keystrokes required to type a word or phrase and therefore increase speed. An extensive abbreviation system can be customized for individual users, thereby retaining the ability to be spontaneous and original. This paper will discuss a system for creating, memorizing and retrieving a large number (2000) of abbreviations.

Background

There is a wide variety of spelling based assistive technologies available to people with speech and/or mobility impairments to help with verbal and/or written communication. Typing out a message or doing correspondence is so laboriously time and energy consuming that users often feel defeated and abandon the device designed to help them. Morse Code for example, is an excellent method for users with mobility impairments but typing out each word is tedious.

Frequently software comes with pre-programmed phrases like "I am hungry" or "I like you" but these rarely convey more than basic wants and needs. They do not allow any spontaneity or self-expression. In addition, computer operations are not usually included; they are difficult to perform and mistakes are easily made during the execution of lengthy sequences of commands.

Statement of the problem

Forms of assistive technology exist for augmentative communication but many spelling-based systems share common limitations: spelling every word is time consuming and, pre-programmed messages limit free-flowing, individualized expression. A model for an extensive abbreviation system has been created which addresses these limitations.

Approach

After finding the appropriate hardware and software for the individual user, rehabilitation personnel can take on the role of guide as the user begins to build his/her own extensive abbreviation system. The guide will introduce the user to the notion of using abbreviations to increase speed. Abbreviations consist of two or three characters which expand to form written or spoken words, phrases or expressions. Some abbreviations will perform computer operations. The small number of keystrokes, compared to the tremendous output, accounts for the difference in efficiency. Abbreviations can cut the time required to produce a given body of work by up to 65 percent. Memorizing an already existing list would be a daunting task. When there is a basic model or framework the individual can then customize it. In addition, because individuals design their own abbreviations, they are more likely to learn them than they would someone else's list.

The purpose of the model is to provide the user with an easy way to access a large number of abbreviations. The model makes learning many abbreviations manageable. He/she is directed to pay attention to the kind of language used in ordinary communication. Anything used frequently should become an abbreviation. Words such as "because", "from", and "this" or combinations like "there is", "most of the", or "that was" are essential in all communication and should therefore be abbreviated.

The rest of the system is more personalized. Abbreviations are added to the system as the user notices any pattern of speech which is used repeatedly. The users themselves select the matter to be abbreviated as well as the form that will be the easiest to retrieve from memory.

Computer operations can also be abbreviated. As in macros, complicated or lengthy sequences can be performed through the use of abbreviations which require only a few characters. Operations as simple and frequently performed as "save", "save and quit" or as complicated as appending a second file to an original file can be done using abbreviations. This saves many keystrokes and avoids errors. As with the other abbreviations, mnemonic techniques must be created by the user to simplify learning and retrieval.

The model is based on encoding and consistency and can simplify memorization. Each user will have a preferred mnemonic encoding approach but it is essential that the same method be used throughout the abbreviation system.

One method is to utilize symbols as part of the abbreviation. Using symbols eases memorization demands because knowing the symbol for a category will instantly trigger awareness of one character of the abbreviation. The symbol, such as the apostrophe ('), or asterisk (*) can stand for a category or small number of categories of items to be abbreviated. For example, the greater than sign (>) indicates expressions with time "a long time ago" could be lo>, "from time to time" could be fr>, "for awhile" fw> and the "last time" could be la>.

Similarly, if the asterisk is used for short words and greater for longer ones consistency makes it clear that if eq* is "equip" and ps* is "Please say hello to", then eq> is "equipment" and ps> is "Please say hello to everyone for me".

Implication/Discussion

Having an extensive abbreviation system can dramatically reduce the time required to produce augmentative speech. My system, which consists of more than 2000 abbreviations enables me to "type" at a rate of 45-50 words a minute. It also permits communication that is customized and individualized. This allows a person who may be without speech to communicate in language under his/her control.

An extensive abbreviation system enables the user to have spontaneity and freshness of communication that is not possible using pre-programmed abbreviations. Individuals could have a group of abbreviations for both formal and informal correspondence and conversation. When writing or speaking about a particular topic in which special vocabulary is needed, additional abbreviations can be made following the same mnemonic pattern.

An obvious limitation is that its usefulness, to a large degree, depends on cognitive ability. Some individuals would be unable to remember a large number of abbreviations.

Geri Esten - 6350 W. 80th Pl.
Westchester, CA 90045
(310) 337-9235

COMPUTER-ANIMATED SEQUENCES AS AN INSTRUCTIONAL AID IN WHEELCHAIR PROPULSION MECHANICS

José Colucci Jr.* and Marty Morse*
Universidade de São Paulo, Brazil * and University of Illinois at Urbana-Champaign, USA*

ABSTRACT

The Illinois Para-backhand is a radically new wheelchair propulsion technique developed to reduce stress-related injuries associated to high-intensity wheelchair propulsion. It has been in use for more than three years and has succeeded in reducing the frequency of injuries without undermining performance. Teaching the Para-backhand is now part of regular workshops and clinics sponsored by the University of Illinois. The Para-backhand, however, is a complex movement and a very difficult one to explain without visual aids. Short computer animations were created to simplify the understanding of the Para-backhand mechanics. Starting with biomechanical analysis of video; body measurements, positions and angles were translated into a CAD drawing and animated according to the procedures described in the paper. The final product is a set of five short animations that run on any PC with a VGA screen or better. Coaches and athletes that have used this instructional aid consider it to be more effective than either video tapes or schematic drawings as a means to teach this new wheelchair propulsion technique.

BACKGROUND

High-intensity wheelchair propulsion is potentially injurious to upper extremity joints due to the repeated and forceful impact of the hands against the pushrims. Rigorous training has been associated with stress-related injuries to the wrists, fingers, thumbs and elbows. In an attempt to reduce these injuries without undermining performance, biomechanical studies conducted at the University of Illinois resulted in the development of a radically new propulsion technique (Morse *et al*, 1994). Known as Illinois Para-backhand, this technique is characterized by contact along the distal surface of the fingers with base support provided by the thumb as opposed to conventional-stroke-mechanics, where contact occurs at the index and middle fingers and the base of the thumb. To accommodate these altered stroke-mechanics, a specialized racing glove (Harness Designs) was also developed. Made of materials that provide greater adhesion to the pushrims, along with greater stability and protection for contact points, the Harness glove is much gentler on the hands than the commonly-used handball gloves wrapped in tape or elastoplast.

The Para-backhand can be partially credited for the U. of I. Wheelchair Racing Team's outstanding achievements. During the last three years in which it has been in use, the frequency of injuries has decreased and individual performances have improved.

Teaching the Para-backhand is now part of regular workshops and clinics sponsored by the Division of Rehabilitation Education Services (DRES) of the University of Illinois at Urbana-Champaign. Learning the mechanics of the Para-backhand, however, can be a challenge for people used to the conventional-stroke-mechanics. Each of the Para-backhand five basic phases calls for a precise positioning of the fingers, wrists, arms, elbows and shoulders in relation to both the pushrims and the upper body. This complex tridimensional movement pattern, involving simultaneous action at several joints is difficult to convey without visual aids. Video tapes, schematic drawings and actual demonstrations by athletes have been used in the past, but computer-animated sequences proved to be superior to these methods for teaching purposes.

OBJECTIVE

The main objective was to develop short computer-animated sequences to be used as a visual aid in teaching the Para-backhand at the clinics and workshops sponsored by the DRES and to be distributed by mail as shareware. To meet these objectives, the animations needed to be true to the actual movement pattern, be able to run on widely available hardware and fit into a single diskette for inexpensive delivery. This paper is a description of the procedures used to translate the results of the Para-backhand biomechanical analysis into a format that satisfied these requirements.

METHOD

The starting point for the animations was actual footage of wheelchair races. Several different sequences of frames selected by the coach as being examples of good propulsion technique were analyzed and joint angles and positions determined with relation to a known reference. Using a standard S-VHS format we had 15 fps, which was considered high enough a sampling frequency for our purposes.

The procedure was refined later by three-dimensional video analysis of athletes pushing a racing wheelchair mounted on a roller ergometer. Markers were positioned on the athletes' third metacarpal, epicondylus lateralis, acromion and processus spinosus of C7. Recordings were made from the left and the front side of the participant by means of two cameras at 90° connected through an electronic event synchronizer. This way, spacial information could be retrieved from the combined two-dimensional information from the sagittal and frontal planes.

The human figure representing the athlete was drawn in Mannequin V1.1 (HUMANCAD - Biomechanics Corporation of America). Since this program allows each of the body parts to be adjusted for a different percentile, a smaller percentile was used for the lower body than for the upper body for a better anthropometrical simulation of a typical wheelchair athlete.

After being set into a suitable starting position, the human figure was exported to AutoCAD V.12 (AutoDESK) in DXF format and positioned over a racing wheelchair previously drawn in 3-D (Fig.1). This step was needed for precise scaling of both the human body and the wheelchair. Some editing was necessary to remove unwanted detail and to group body parts and mechanical components of the chair into blocks suitable for the next step. The drawing was then re-exported in DXF format to 3-D Studio (3DS, AutoDesk).

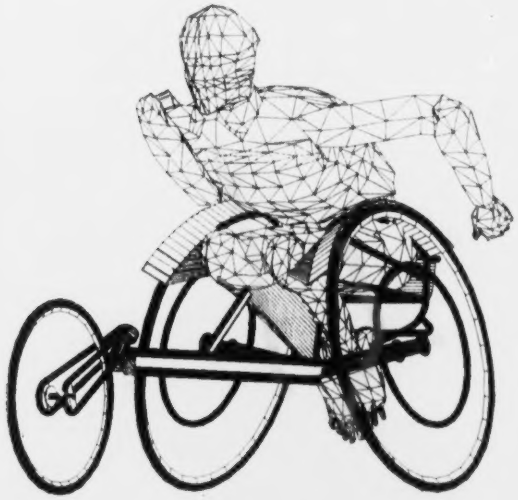


Fig. 1: Wireframe model in AutoCAD

Figures imported from Mannequin into 3DS have a very faceted look and holes in some joints. 3DS Editor tools were used to smooth out surfaces and weld open joints. In the same module, each object was assigned the appropriate material. The Illinois Track Team logo was drawn as a bit map, saved as a material, and applied as a mapping to the figure's chest to simulate the team's jersey. The same procedure was used to place the sponsor's logo on the wheelchair frame. For certain sequences, a scenery containing trees, road surface, grass and a cloudy sky was added for greater realism. When still renderings generated by this module were considered satisfactory, the set was animated in the 3DS Keyframer. In this module, the body parts are linked to form a hierarchy of objects in which all "child objects" move along with their "parents". This way, for example, a movement of the arms cause the forearms, hands and fingers to move. The most difficult part is to place the pivots in suitable points so that the linked parts move in a natural fashion. We found later that even when pivot positioning is carefully done, the resulting movements can be considered at best approximate. Still in the Keyframer module, 15 preview frames were rendered. Since we needed the animation to be a precise depiction of the actual movement, each of the resulting frames was manually adjusted to match corresponding frames on the actual video footage. The final sequence was fine-tuned by the coach to represent an ideal movement pattern, with some emphasis added to certain desirable features as having the head facing forward and lifting with the upper-back muscles. After the positioning of lights and cameras, this biomechanically correct sequence was used to generate several different animations (flics) in AutoDesk's FLI format, including front, side and perspective views, close-ups of the hands and a realistic sequence of a racer (Fig. 2). The animations were rendered at 320x200 pixels by 256 colors. The next and final step was to edit the animations using Animator Pro (AutoDesk). In this program, individual frames were retouched to eliminate artifacts and special effects such as movement blur and legend animation added.

RESULTS

The final product is a set of five flics that fit into a single 3½" diskette along with the Animator Player, a free-distribution player program by AutoDesk. The animations can run on any PC with a VGA screen or better. Since the FLI format is supported by the Windows Multimedia Extensions, they can also be played on any Windows Multimedia System or integrated into Multimedia databases.

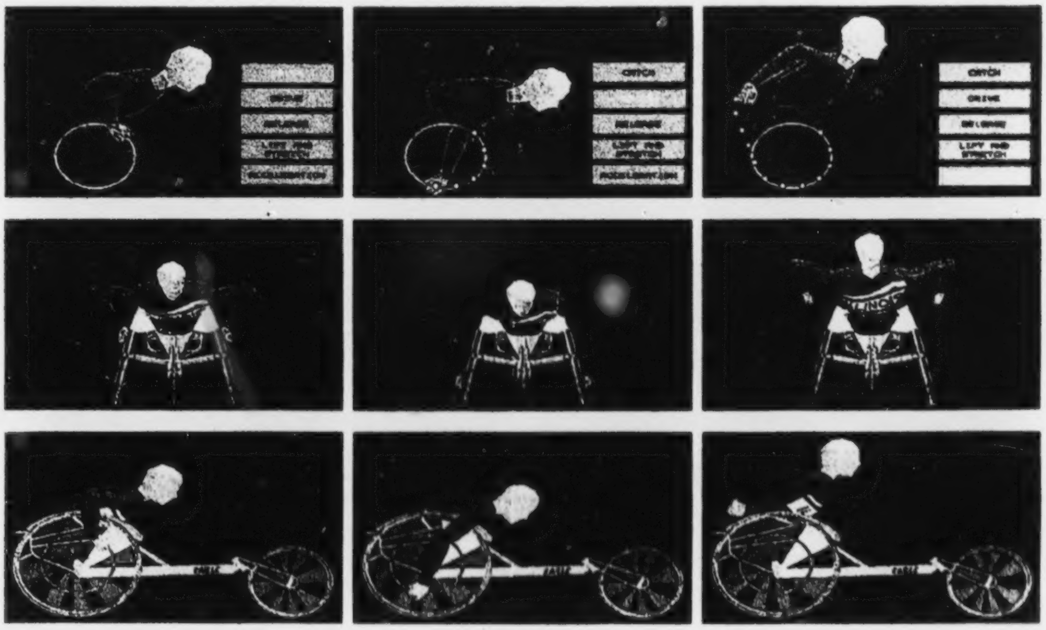


Fig 2 Selected frames from animations (a) Top: five phases, (b) Center: front view and (c) Bottom: side view

DISCUSSION

The effectiveness of the animations for coaching was assessed through questionnaires which the participants of the workshops were requested to answer. It is general opinion that, as a visual aid for teaching the Para-backhand, these short animations proved to be far better than either videos or schematic drawings. They can be played at any speed from faster than real to slow motion in a consistent and repeatable manner. They can also be paused at any particular frame for detailed observation. The decomposition of the stroke into five phases, difficult to explain by other means, can be clearly seen. Since the human figure is shown without gloves on the animations, they have over actual demonstrations the advantage of showing precisely the contact points between the fingers and the pushrim and their dislocation within the stroke.

The use of these computer-animated sequences has greatly reduced the time it takes to explain the basics of the Para-backhand and has been praised by coaches and athletes as a simple and effective means of conveying an otherwise difficult-to-teach technique.

REFERENCES

Morse, M.; Millikan, T. and Hedrick, B. *The Para-backhand pushing technique*. Sports 'n Spokes, 20(1): 58-60, May/June 1994.

Software used: Mannequin® by HumanCad, AutoCAD V.12 ®, 3D-Studio 1.0 ® and Animator Pro ® by AutoDesk.

ACKNOWLEDGEMENTS

During the development of the animations, the first author was partially supported as a visiting scholar with the University of Illinois at Urbana-Champaign by a grant from CAPES - Ministry of Education - Brazil.

José Colucci Jr., Assistant Professor
FAUUSP - Universidade de São Paulo
Rua do Lago, 876
05508-900 São Paulo, SP - Brazil
Fax: (011) 813.2932
Email: jcolucci@cat.cce.usp.br

BEST COPY AVAILABLE

PROVIDING AAC DEVICE ACCESS TO THE MACINTOSH

Mark E. Novak[1] and Aimee J. Luebben[2]
[1]Trace Center, University of Wisconsin, Madison, Wisconsin
[2]University of Southern Indiana, Evansville, Indiana

ABSTRACT

Because of physical disabilities, some people are unable to use standard keyboards and pointing devices (e.g., mouse); however, if they are augmentative or alternative communication (AAC) device users, they could use these devices to access computers. Unfortunately, most computers are designed to receive input from the user via the keyboard and mouse, not through an AAC device connected to the serial port.

The Macintosh version of SerialKeys, like its DOS and Windows predecessors, converts data arriving at the serial port into keyboard and mouse events in the computer. SerialKeys follows the general input device emulating interface (GIDEI2) proposal (1), thus providing users with the same SerialKeys access to the Apple Macintosh that they have for IBM computers running DOS/Windows.

BACKGROUND

In the past few years, there have been many improvements in the area of "built-in" or "out-of-the-box" computer access features for individuals with physical disabilities. One example is Apple's Easy Access, a software utility that ships with the Macintosh operating system. Easy Access includes features such as StickyKeys, which allows the single-finger typist to perform multiple simultaneous keystrokes (e.g., "command-q" in sequence); SlowKeys, which allows a user to adjust the sensitivity of the keyboard to lessen the chance of pressing the wrong key; and MouseKeys, which allows a user to perform all the actions of the pointing device (e.g., mouse) using the numeric keypad keys.

Despite these enhancements, some people still cannot use the standard keyboard and mouse because of physical disabilities, but could use their AAC devices to access computers. Many AAC devices are equipped with external connector(s) or serial ports, allowing for a connection to a computer's serial port. A typical computer, however, is designed to receive input from the user via the keyboard and mouse, not through the serial port. Therefore, simply connecting an AAC device to the computer's serial port will not allow the user to access or operate the computer.

As IBM and Apple personal computers became more powerful and numerous, and less expensive in the 1980s, especially in the education and business arenas, more AAC device users found themselves in need of computer access. Unfortunately, when AAC device users wished to connect to a personal computer, they were usually forced to contact the AAC device manufacturer, each of whom in turn was left with the problem of creating computer or operating system specific hardware or software to make the AAC device-to-computer connection.

In an effort to solve this access problem, the keyboard emulating interface (KEI) concept was proposed (2). Essentially, the KEI concept was the first attempt to split this computer access problem into two manageable parts: a) the external connection and communication protocol which was non-computer specific and b) the injection of information into the operating system to emulate keyboard events which was computer specific. By separating the connection and communication protocol from the computer hardware and operating system, AAC users could utilize their devices to access different computers. In other words, the same protocol or "language" preprogrammed on their AAC devices could be used to access different computers, thus eliminating the need for constant device reprogramming. Also, AAC device manufacturers would no longer be required to develop their own protocols. However, because the KEI did not interpret or decode the communication from the AAC devices into the specific computer or operating system equivalent keyboard events, there was still some burden on the AAC device manufacturers.

The "K"EI was eventually replaced by the "GID"EI ("keyboard" versus "general input device" emulating interface), shortly after the introduction of the Macintosh and PS/2 computers, due to the fact that keyboard access alone would no longer provide complete computer access. Both the Macintosh and PS/2 computers included non keyboard input capability in the form of a pointing device, commonly called a mouse. The GIDEI provided communication protocol that allowed for more generalized input devices, especially pointing devices such as the mouse.

STATEMENT OF THE PROBLEM

However, the problem of creating specific computer or operating system hardware or software to handle or decode the AAC device-to-computer information arriving at the serial port was still unsolved. After developing several such computer or operating system "specific" implementations, the Trace Transparent Access Module (T-TAM), an operating system independent and also Macintosh or IBM compatible hardware device, was developed. T-TAM provided the necessary AAC device-to-computer translation or decoding of information for both the IBM PC and Macintosh platforms. Since this AAC device-to-computer translation of information occurred via a serial port, the feature became known as "SerialKeys." SerialKeys basically translates the AAC device-to-computer messages which follow the GIDEI communication protocol into the appropriate keyboard and mouse events on the computer.

RATIONALE

When Apple originally developed Easy Access, SerialKeys was not included. Several software or combination hardware/software devices which support SerialKeys have appeared on the market, each capable of interfacing to the Apple Macintosh (e.g., Macintoshs equipped with the Apple Desktop Bus), the least expensive being the T-TAM which is available for about $500.

During the same time, however, both IBM and Microsoft have introduced "free" SerialKeys software solutions: AccessDOS and the Access Pack for DOS and Windows respectively. Microsoft is also beta testing the next release of their desktop operating system known as Windows 95, which has a built-in version of SerialKeys. AAC device users, therefore, were requesting a similar solution be provided for the Macintosh.

DESIGN

The Macintosh version of SerialKeys is designed to provide the same functionality as its DOS and Windows predecessors. The AAC device, using the GIDEI protocol, transmits information to the Macintosh computer. SerialKeys then processes that information to determine which keystrokes to type or what mouse actions to perform on the Macintosh computer.

DEVELOPMENT

The GIDEI protocol has two modes of operation for sending keystroke and mouse information: Character Mode and Escape Sequence Mode. Character Mode is used for typing characters (e.g., to type a character means to emulate the press and release of a key as if the user had actually "typed" on the keyboard). To type characters, simply send that character which is sometimes referred to as an "ASCII character," from the AAC device to the computer running SerialKeys. Some examples of ASCII characters are the lowercase letters "a-z"; uppercase letters "A-Z"; most common punctuation characters like comma ","; period "."; etc., and the numbers "0 through 9." Typing characters does not require any special action on the part of the AAC device user. For example, to type an "a" key on the computer, the AAC device should send the ASCII character "a" to SerialKeys.

Escape Mode is used for typing specific keys or those keys which do not have an ASCII character name (e.g., pageup, home, etc.), for keyboard commands, for mouse activity, and for other miscellaneous GIDEI commands. Escape Mode is entered by sending an ESCAPE character, which marks the beginning of an escape sequence. An escape sequence is simply the ESCAPE character (ASCII 27, represented as "<esc>" below), followed by a sequence of other ASCII characters, and ending with the PERIOD character (ASCII 46, "."). Since each key is designated by a key name, the user can type any key by using that key name in an escape sequence. For example, to type the "pageup" key, the user needs to use an escape sequence with the key name for the "page up" key as follows: *<esc> pageup* .

Other keyboard actions may involve the typing of multiple keys simultaneously, or typing keys which are used to "modify" other keys when used together, such as the "shift" key. To perform these types of keyboard actions within escape sequences requires the use of a keyboard command. Escape sequences for keyboard commands would use the general form: *<esc>, command name, key name.*

MACINTOSH AAC DEVICE ACCESS

Escape sequences are also used to send mouse commands from the AAC device to SerialKeys. This includes all mouse actions such as button clicks, click and drag, cursor movement, etc. New mouse commands which allow for saving cursor positions to facilitate faster navigation in the Macintosh graphic user interface have also been added to the protocol, with the first full implementation in SerialKeys for the Macintosh.

EVALUATION

At the time of this paper, the SerialKeys software for the Macintosh has undergone alpha testing, and is being shipped for a first beta test at multiple sites around the country.

DISCUSSION

With the development of SerialKeys for the Macintosh, the users of AAC devices linked to Macintosh computers no longer must purchase a combination hardware/software device interface. They can join the many AAC users already using SerialKeys, the "free" software solution to access DOS and Windows on the IBM platform.

REFERENCES

1. Standards Project Manager, (1994) "General Input Device Emulating Interface, GIDEI2 Proposal (Draft Version 2.0)," Trace R&D Center Reprint Service, Trace Center, University of Wisconsin Madison.

2. Vanderheiden, G. (1980) "Practical Applications of Microcomputers to Aid the Handicapped," in Computer IEEE Computer Society, January. (Invited)

ACKNOWLEDGEMENTS

Funding for this project was provided by Apple Computer and the National Institute on Disability and Rehabilitation Research (grant number H133E30012).

Mark Novak, Project Engineer
Trace R&D Center, Waisman Center
University of WI-Madison
Madison, WI 53705-2280
608-262-6966, 608-262-8848 fax, 608-263-5408 tdd,
menovak@facstaff.wisc.edu

MCDC: THE FIRST INPUT PC CARD

Aimee Luebben[1] and Mark Novak[2]
[1]University of Southern Indiana, Evansville, IN
[2]Trace Center, University of Wisconsin, Madison, WI

ABSTRACT

With the trend of downsizing to increase the portability of notebook and subnotebook computers, comes a new Personal Computer Memory Card International Association (PCMCIA) bus which accepts flat cards that look like credit cards. Designed at first as memory expansion, the PCMCIA bus and cards now permit new levels of transparent access to computer systems. The transparent access capability of the PCMCIA bus offers many options to individuals with disabilities who need personalized computer input systems. This paper discusses the Morse Code Darci Card (MCDC), the first input PC Card (formerly called PCMCIA card) designed for persons with disabilities.

BACKGROUND

For years educators, service providers, and people with disabilities have worked to eliminate physical barriers (1). Rather than providing enhanced access for persons with disabilities, the advent of computers increased the number of barriers further and also invented a new type: the electronic barrier. When persons with physical disabilities often found standard keyboards difficult or impossible to activate, alternative input devices were designed to work in place of the keyboard and pointing device (e.g., mouse) (2). Many of these alternative input devices (switches, membrane keyboards, etc.) cannot work alone, but require attachment to an "emulator" or formally, a general input device emulating interface (GIDEI), called a keyboard emulating interface (KEI) in the 1980s.

In the early 1980s, the choices for GIDEIs were few, but during the golden age of emulators later in that decade, there were over 20 GIDEIs available from more than 10 companies (3). Since that time, some companies have designed more sophisticated GIDEI products to replace earlier versions while other GIDEI businesses have gone bankrupt. At a time when there are fewer devices and companies, the match between the device and user is critical for the selection of the best GIDEI. A recent presentation provided features to consider when selecting a GIDEI including: a) true versus partial emulation, b) mouse emulation, c) support of basic access options, d) support of advanced access options, e) support of computer platforms, f) support of operating systems, g) transparency, h) modular versus system, i) health of the company, and j) price (3).

STATEMENT OF THE PROBLEM

In many cases, GIDEI designers sacrifice footprint size to gain access transparency. For someone who uses a desktop computer system in the home, school or office, adding a GIDEI (some devices measure 9 inches wide by 10 inches long by 2 inches high and weigh more than one pound) to the desktop does not present difficulties. For a person with disabilities who uses a notebook or subnotebook computer because of the mobility capabilities, however, the size of the emulator is the problem as the GIDEI may exceed the dimensions of the portable computer system to which it is interfaced. Size, including the physical properties of shape, weight, and bulk, is an eleventh feature to consider when selecting a GIDEI system mobile communication and access needs.

RATIONALE

PCMCIA technology provides an answer to the size problem inherent in many GIDEI devices. For persons with disabilities, who use notebook and subnotebook computers, PCMCIA technology makes it possible to have a credit card sized emulator that fits within the case of the portable computer system rather than attaching a separate GIDEI contained in an external box. Combining PCMCIA technology with notebook and subnotebook computing platforms has several benefits. First, the PCMCIA standard defines a card services software layer which offers "plug and play" capability that allows cards to be added or removed (much like the insertion of a floppy disk) from the system without powering off the system or physically opening the computer case. The physical aspect is the second benefit of PCMCIA technology: the cards are lightweight, rugged, and smaller than the equivalent computer bus cards being replaced. Transparent access, the third feature, is available since the PCMCIA socket services software provides a BIOS (Basic Input/Output System) level software interface to the computer.

DESIGN

Currently the PCMCIA standard defines three PC Card types which differ basically in thickness: Type I (3.3 mm thick), Type II (5.0 mm thick), and Type III (10.5 mm thick). Not yet a part of the PCMCIA standard, a 16 mm thick Type IV PC Card was recently adopted by the Japan Electronics Industry Development Association. All PC Cards are 85.6 mm long and 54 mm wide with the exception of Type I and II extended cards which are approximately 40 mm longer. Since all PC Cards use the same 68 pin edge connector and basically differ in only thickness, a card with a lower type number can be utilized in a socket with a higher type number (e.g., a Type I PC Card can be used in a Type II or III socket, but a Type III card is too thick for a Type I or Type II socket). After the July 1993 2.1 release of the PCMCIA standard which provided the BIOS level software interface to the computer, PCMCIA capable notebook and subnotebook computers and PC Card products started to appear in volume. Today, the majority of notebook and subnotebook computer vendors offer PCMCIA capabilities, and users may purchase a PC Card which can provide megabytes of flash memory, RAM memory, hard disk space, or can perform as a LAN adapter, SCSI adaptor, data/fax modem, or even a sound card.

At this time, the first available assistive technology input device based on the PCMCIA standard is the Morse Code Darci Card (MCDC) from the Darci Institute of Rehabilitation Engineering, a component of WesTest Engineering Corporation (1470 N. Main, Bountiful, Utah, 84010, 801-298-7100, 801-292-7379 [fax]). Designed for IBM computers, the MCDC is a Type II PC Card which emulates all keyboard and mouse input events, and is compatible with DOS, Windows and OS/2. The MCDC comes with installation software on disk and an input device interface cable, and supports the use of switches (one, two, or three), proportional joysticks, and serial pointing devices (e.g., a mouse or a trackball) compatible with a PS/2 mouse.

DEVELOPMENT

Several powerful features allow the user to customize the MCDC to meet his or her needs. One feature is the ability of loading a file with precustomized parameters. This ability to load other files permits an evaluation center the opportunity of saving files for multiple patients or clients. As another feature, a user can select the input device and the number inputs as well as adjust the timing. Adjustable timing features include the dot/dash timing, end of character timing, typematic repeat, and typematic delay. Typematic rate is the time involved in sending a single character to the screen while typematic delay allows the user to determine how long the MCDC will wait before entering the typematic mode, the repeating of a string of characters when a key is continually pressed on keyboard.

A third feature permits the user to adjust the mouse pointer in terms of speed/sensitivity, double click speed, acceleration, reorientation and mode (direct or Morse code) and also to customize the mouse by swapping buttons (the left button becomes the "right" button and vice versa). By reorienting a pointing device, a person with more functional movements toward the body could have the "up" mouse action reoriented to be "down" toward the body). Customizing auditory and visual feedback are other features of the MCDC. The auditory feedback can be adjusted in the sound option with the user having the opportunity to select the sound source (the computer speaker is the default setting), set the volume, and decide the sound time generation and frequencies of the dot and dash. The user can also choose to have visual display feedback by selecting to display the code on the screen and by specifying both the display location and size of the visual display on the screen.

To enhance productivity, one of the most powerful features of the MCDC is the ability to select up to 99 alternate Morse code sets. At present, standard Morse code exists for most ASCII characters, numbers, and some punctuation, but many computer keys (and mouse movements) fall outside the standard ASCII character set. Since Morse code has variations for some alternate input devices, the alternate Morse code option allows the user who switches from a different Morse code input device to the MCDC the opportunity to utilize a set of Morse code definitions he or she already knows. For efficiency in a specific software application, users may also wish to design a different code set. For example, in a game that uses two keys, an enter key and space bar, the user could define and save a new code set that designates "*" as enter and "-" as space rather than inputting "*-*-" for enter and "**--" for a space as in the default MCDC code set.

Another power feature for the user is the ability to use Darci macros which are programmed the same way as code sets. Darci macros can be used to output anything; however, most people think of basic macros as productivity enhancers because a character can be assigned (for the MCDC, any combination of eight dots and dashes can be assigned) to frequently used strings of characters such as name, address, phone numbers. The MCDC has more advanced macros that will allow the user not only to input complex combinations of text, but also to launch a program and enter the beginning "keys" required by the beginning of the program, all with the entry of a single eight dot/dash macro command. With the possibility of 512 codes and/or macros per code set and 99 user defined code sets, the variations are almost endless.

EVALUATION

At the time of this paper, the MCDC has undergone alpha testing, and is being prepared for beta testing at multiple sites around the country.

DISCUSSION

For consumers with disabilities who use notebook or subnotebook computers, size (including the physical properties of shape, weight, and bulk), becomes an eleventh feature to consider when selecting a GIDEI. With credit card sized PC Cards, PCMCIA technology provides an answer to the size problem encountered in many GIDEI devices. The MCDC, developed by WesTest Engineering, is the first input PC Card designed specifically for persons with disabilities. With the advent of PCMCIA technology and the potential possible with the evolving PC Card standard, including the development of the CardBus (which consists of a 32 bit data path, bus-mastering capability, support for multifunction and low voltage PC Cards) and built-in operating system support, persons with disabilities could see many other PC Card products (input, output, software) available for notebook and subnotebook computers in the near future.

REFERENCES

1. Luebben AJ. Alternate computer access. *Rehab Management*, 1990: 3(5)41-46, 49.
2. Luebben AJ, Oeth RB. Alternate input access: A comparison of emulating interfaces. *Closing The Gap*, 1990: 9(2)24-25.
3. Luebben AJ. Darci Too: The keyboard emulating interface for the maximum connection. In H. J. Murphy (Ed.), *Technology and Persons with Disabilities*. Northridge, CA: California State University Press, 1994.

IBM, PS/2, and OS/2 are trademarks of International Business Machines. Windows is a trademark of Microsoft Corporation. Darci Cards and Morse Code Darci Cards are trademarks of the Darci Institute of Rehabilitation Engineering.

Aimee Luebben
Director and Assistant Professor
Occupational Therapy Program
University of Southern Indiana
8600 University Blvd.
Evansville, IN 47712
812-465-1179
812-465-7092 (FAX)
aluebben.ucs@smtp.usi.edu

Mark Novak
Project Engineer
Trace R&D Center
University of Wisconsin-Madison
S159B Waisman Center
1500 Highland Avenue
Madison, WI 53705-2280
(608) 262-6966
menovak@facstaff.wisc.edu

INTERACTIVE COMPUTER VIDEO: A TRAINING TOOL FOR DYNAMIC PROSTHETIC ALIGNMENT

David A. Boone CP, Aaron W. Joseph MS, David E. Mathews CP, Douglas G. Smith MD
Prosthetics Research Study
Seattle, WA USA

ABSTRACT

Repetition is an important element in training prosthetists to be competent in clinical gait analysis and diagnosis of amputee gait deviations. By storing video clips of amputee gait we have created an interactive simulator of amputee gait dynamics (Figures 1,2). It provides a computer simulated gait training area for the user to interact with a tireless "virtual patient." The student can adjust the alignment of a prosthesis on the computer screen and instantly see pre-recorded video of the amputee with that alignment. Likewise, the system can present an amputee with gait deviations for the student to correct. Multiple patients and pathologies can be represented on a single computer compact disk (CD-ROM) for widespread inexpensive distribution. This simulator software can be a valuable training tool for other rehabilitation professionals as well.

BACKGROUND

Proper gait of lower limb amputees is critically dependent upon the precise alignment of the prosthetic socket over the supporting foot. Prosthetists align artificial legs in two steps. They perform static or bench alignment during construction of the prosthesis. Then they perform dynamic alignment by making fine adjustments while observing the patient walking with the prosthesis.

Understanding the nuances of dynamic alignment of lower limb prostheses and amputee gait requires a great deal of training and clinical experience. Watching gait training films showing defined gait deviation in a single amputee is a well known method to train prosthetists and other rehabilitation professionals (1). A film does not, however, allow the viewer to interact with the presentation beyond stopping and rewinding the film. Computer-based digital video with the appropriate software allows the viewer to quickly access any stored images.

Recently, interactive multimedia presentation of pathological gait has been shown to increase the effectiveness of the clinical gait analysis instruction for orthopaedics. Two systems similar to our simulator have been developed at the Ohio State University gait analysis laboratory (2,3). These systems have specifically been geared to teaching skills in clinical gait analysis of musculoskeletal pathologies. Both Ohio State systems use the same underlying digital video retrieval technology used in this software project.

STATEMENT OF THE PROBLEM

Create an interactive video database to help train prosthetists and other rehabilitation professionals in the dynamic alignment of lower limb prostheses.

RATIONALE

Learning about dynamic alignment by experimenting with an actual patient's prosthesis is time consuming, expensive, and uncomfortable for the patient. An interactive computer video gait simulator overcomes these problems, allowing a prosthetist to endlessly experiment with a "virtual patient" while learning the fundamentals of this difficult skill.

DESIGN

We developed this gait simulator on a Macintosh computer using the Apple QuickTime digital video format and the Apple HyperCard database development environment. QuickTime and HyperCard were chosen because they are easy to use, well-supported, and standardized (both QuickTime and HyperCard are supplied with all Macintosh computers). HyperCard allows a programmer to quickly create user-friendly interfaces and provides easy access to sophisticated multimedia features such as video, graphics, and sound.

The software can be used in "practice" or "testing" modes. In the practice mode the user adjusts the alignment of the prosthesis using controls in the left panel and then sees the effect on with the video clip of amputee gait in the right panel (Figure 1). In the testing mode the software randomly selects a particular alignment problem and displays the associated video clip. The user must then diagnose the problem and choose the correct adjustment in the left panel (Figure 2).

The video gait simulator software will be distributed on CD-ROM because of the size of the digital video files. One CD-ROM can store approximately 500 video clips of 14 seconds each. Adjusting the quality of the digital video can significantly increase or decrease the number of video clips that can be stored.

DEVELOPMENT

The video clips in this first prototype were copied from a classic training film (1). The video was digitized, compressed, and edited. The programming was all done in HyperCard and centered on designing a straightforward, intuitive user interface and rapid accessing of video clips.

EVALUATION

This prototype software will be distributed on CD-ROM to a small number of prosthetics teaching programs to get feedback on the design and content. A second version of this video gait simulator will incorporate video filmed especially for this project, including a wider variety of amputee subjects and other improvements based on the feedback from the first prototype.

DISCUSSION

We envision our system being used in the same way that simulators are used to give pilots more experience in the cockpit than is practical to provide in real aircraft. The system may also be a beneficial tool for component manufacturers to familiarize clinical prosthetists with the alignment and performance of new devices through experiences with "virtual" patients. We believe that computer-based interactive video databases can be a valuable training tool for professionals in many other fields as well.

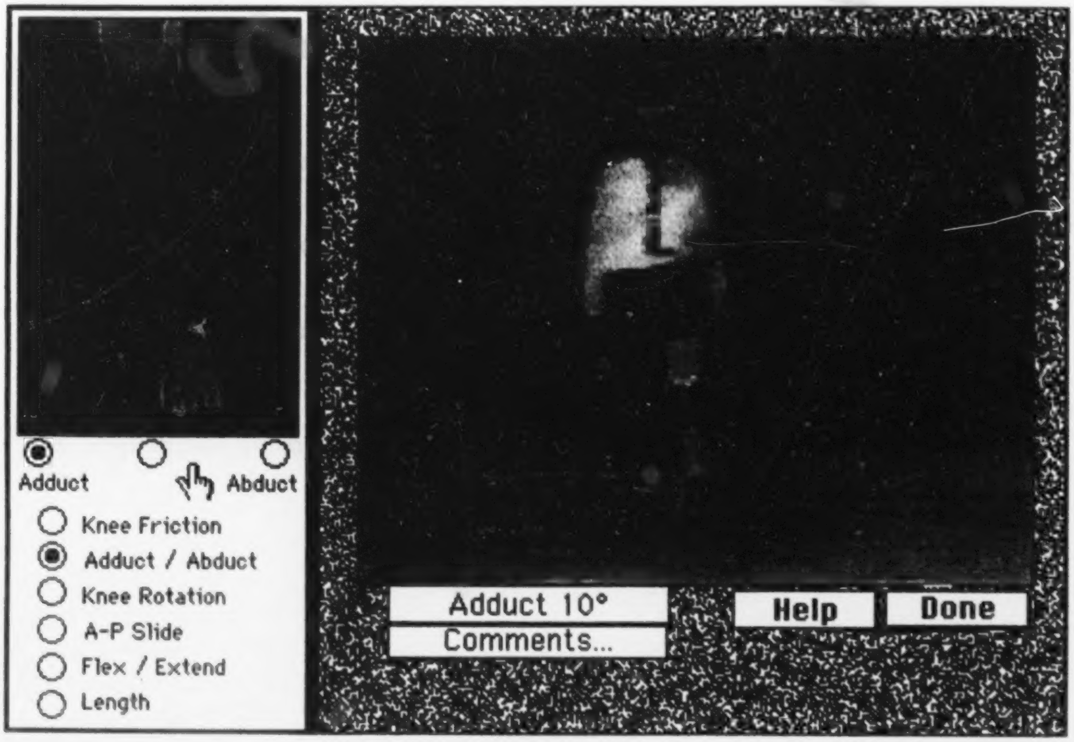
REFERENCES

1. Gait Analysis of the Above Knee Amputee, (Film) Prosthetics And Orthotics Curriculum, Northwestern University, Chicago.
2. Development of a Computer-Based Multimedia Tutoring System for Teaching Gait Analysis (Master's Thesis), JC Nippa, The Ohio State University Graduate School, Columbus Ohio, 1993.
3. Personal Communication, Peter Quesada Ph.D., Ohio State University Gait Analysis Lab

ACKNOWLEDGEMENTS

We thank the prosthetics education program at Northwestern University for providing the classic training film "Gait Analysis of the Above-Knee Amputee" for this prototype. This work was funded by the US Department of Veterans Affairs Rehabilitation Research and Development Service.

David A. Boone
Director, Prosthetist
Prosthetics Research Study
720 Broadway
Seattle, WA 98122 USA
(206) 328-3116 FAX: 325-3607



● Adduct ○ ○ Abduct

○ Knee Friction
● Adduct / Abduct
○ Knee Rotation
○ A-P Slide
○ Flex / Extend
○ Length

Adduct 10°

Figure 1

BEST COPY AVAILABLE

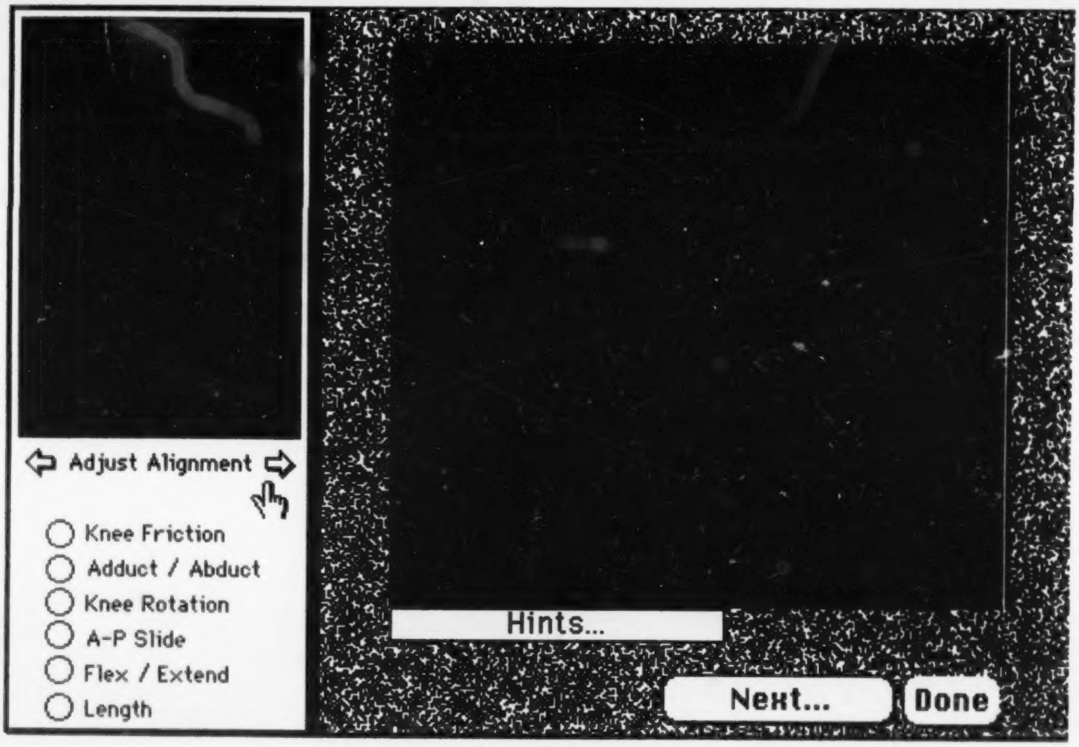


Figure 2

BEST COPY AVAILABLE

The Bloorview Entertainment Plus : Multi-Modal Access to Infrared Controlled Home Entertainment Devices, Lights, and Appliances.

Larry Silver, Ed Snell, CET., Chris Ridpath
Bloorview Childrens Hospital
Willowdale, Ontario, CANADA.

ABSTRACT

One of the most important quality of life issues involved in independent living is access to home entertainment equipment, lights, and appliances in the living environment. People with severe disabilities who lack the physical strength or dexterity to operate commercially available technology, such as hand-held controllers, are forced to rely on attendant assistance to control these devices for them. The Home Entertainment Plus is a preprogrammed infrared controller which allows someone with severe physical disabilities to control 8 home entertainment devices such as TV's, VCR's, STEREO's , and 16 lights or appliances. Direct access is provided through 1 to 3 momentary switch inputs using various scanning strategies. Indirect access is provided through serial communication with a personal computer and a menu based system or other serial devices.

PROBLEM / BACKGROUND

Most home entertainment devices, such as TV's, VCR's, STEREO's, are available with infrared remote control by a hand-held controller. The hand-held controller communicates with the home entertainment device through a manufacturer specific coded sequence of infrared light pulses. Home or apartment settings may contain several home entertainment devices, each requiring its own brand specific hand-held controller. As an example, it would be unlikely that a Sony VCR controller would operate a JVC VCR, although some manufacturers have designed their controllers to operate at least one other device. To reduce the number of device specific hand-held controllers, a single universal controller may be used. Unfortunately, commercially available universal controllers are not designed with physically involved people in mind; the buttons require too much force to press and are too close together for selective targeting. As a result, these clients must rely on attendants to control their home entertainment devices for them.

The two basic types of universal controllers are the trainable and the preprogrammed universal controller. The main feature defining these two types of universal controllers is the procedure used to configure them for each piece of home entertainment equipment. The set-up of a trainable universal controller with a piece of home entertainment equipment involves positioning the hand-held controller and the trainable universal controller so that the infrared communication from the hand-held controller will be received by the trainable universal controller. Training of the universal controller is accomplished by pressing the button on the hand-held controller to be trained and the corresponding button on the trainable universal controller. This process is not only lengthy, and sometimes difficult, but requires the user to obtain assistance in configuring the system. Most commercial infrared controls designed for people with disabilities use the trainable approach.

Preprogrammed universal controllers already contain the information necessary to control most brands of home entertainment equipment. To configure a preprogrammed universal controller, a coded number representing each device model and brand is programmed into the controller. Once set-up, the preprogrammed universal controller is ready to control all home entertainment functions. There are two methods to obtain the coded device number. Firstly, the number may be found in the users manual of the universal controller. Secondly, it is possible on some models for the user to scan through the device type library of codes contained in the memory of the preprogrammed universal controller until they find the codes that operates their particular device. It is this last setup feature which makes an adapted preprogrammed universal controller much more attractive to the user than an adapted trainable universal controller. As a result, this type of universal controller is used in the Home Entertainment Plus.

DESIGN CRITERIA

The Home Entertainment Plus was designed to be capable of controlling most home entertainment devices, lights and appliances in an average persons home or apartment. It will control devices within a line-of-sight range of 7-10 meters (20 -30 ft.). A built in timer/clock provides a time of day indication either displayed on the liquid crystal display (LCD) and/or spoken by the ECHO speech synthesizer. The timer/clock may be used for automatic activation of infrared signals at pre-determined times during the calender year. The device supports clients with a wide range of physical disabilities, such as muscular dystrophy, spinal cord injuries, and cerebral palsy. The Home Entertainment Plus may be accessed through momentary ability switches or through a personal computer and is suited to manual or powered wheelchair users.

BEST COPY AVAILABLE

VISUAL DISPLAY

The visual display consists of a 2x16 character, text based, backlit LCD. The backlight of the LCD is automatically controlled by an ambient light sensor to ensure adequate backlight under low light conditions and to conserve power when the backlight is not required. The menu based system displayed on the LCD is comprised of "Functions","Labels", and "Device Lists". An infrared "Function" is equivalent to the activation of a button on a device specific hand-held controller, such as TV VOLUME UP or STEREO MUTE. All of the infrared "Functions" controlling home entertainment equipment , lights, and appliances are assigned a descriptive "Label" by the user. Multiple "Functions" may be assigned to a single "Label". For example, the "Label" LVG RM ALL OFF (living room all off) may contain functions such as TV OFF, and STEREO OFF. A Select of "Label" LVG RM ALL OFF would turn the TV and the STEREO off. A "Device List" is used to group "Labels" controlling the same device, such as the TV or VCR. Any "Functions" described by a "Label" may be activated by scanning to the desired "Label", on a "Device List", and performing a Select. Fixed "Labels" are provided for switching between "Device Lists" and to access user configuration options. The Scan/Select strategy used to Select labels is based upon whether the input method is 1,2,3 switch or joystick input, and on the scanning method. All operational parameters such as scan type, scan speed, and speech output, and all "Label" and "Device List" names may be user configured through same input method for Scanning and Selecting.

INPUT METHODS

The Bloorview Entertainment Plus incorporates 1,2, or 3 switch input. When a joystick is plugged into the joystick input connector, FORWARD, REVERSE, and LEFT joystick direction contacts are physically tied to the three input switches and perform the same function as these input switches. In three switch input, switch 1 scans through the "Device Lists", switch 2 scans through the "Labels", and switch 3 is used for Select. In two switch input, switch 1 is used for scanning "Labels" and switch 2 is used for Select. For single switch users, a combination of long and short activations of the switch is used for Scanning and Selecting. For more details regarding the function of the 1 to 3 input switches see **Table 1 : Scan/Select Strategies Using the Three Scanning Methods**. Auto detect enables the single switch to be inserted into any of the 3 input switch jacks.

Scanning modes available to the user are HOLD scan, STEP scan, and AUTO scan. In HOLD scan, subsequent "Labels" or "Device Lists" are displayed on the LCD as long as the Scan switch is activated. When the Scan switch is de-activated scanning is stopped. During STEP scan, a momentary Scan switch activation causes the next "Label" or "Device Lists" to be displayed on the LCD. In AUTO scan, Scan switch activation and de-activation causes subsequent "Labels" or "Device Lists" to be displayed on the LCD. To stop scanning, the Scan switch must be activated and de-activated. See **Table 1 : Scan/Select Strategies Using the Three scanning Methods**, for more details regarding the 3 scanning methods. Scanning speed, switch debounce, and switch acceptance time for all scanning modes is dependant on the SCAN SPEED set by the user.

SPEECH FEEDBACK (OPTIONAL)

For those individuals who are blind, have low vision, or who are illiterate, the Home Entertainment Plus provides the option of speech feedback using the low cost ECHO speech synthesizer. During scanning, all information normally displayed on the LCD is spoken as synthesized speech. To operate the Home Entertainment Plus using speech feedback, the user simply waits until the desired device function is spoken, and then performs a Select to activate that function. Although the ECHO will pronounce most user created words correctly, the spelling of some words or phrase may have to be altered for improved pronunciation. The Home Entertainment Plus may be used to speak the time of day from a built in clock.

COMPUTER INTERFACE

The Home Entertainment Plus has a serial interface which allows it to be controlled by devices with a serial port, i.e. a computer. Software installed on a computer is set up as a menu based system that is capable of controlling all of the features of the Home Entertainment Plus. The user's computer access system can then be used to control the Home Entertainment Plus. A timer events menu in the software may be used for controlling time dependant events such as VCR programming or morning wake events such as TV ON. The Bloorview Wireless Switch Link is an optional device that will allow someone remote access to the Computer Interface from a wheelchair. Access to the Home Entertainment Plus is not limited to computers, it may be controlled by any device capable of sending serial data such as augmentative communication devices. (For more information on interfacing to the Home Entertainment Plus, or the Wireless Switch Link, please contact the authors.) The computer interface may also be used to upload and download all user configurations for set-up and back-up purposes.

Table 1 : Scan/Select Strategies Using the Three Scanning Methods.

# of Input Switches		Scanning Methods		
		HOLD	STEP	AUTO
1	Scan	Long activation of switch	Short activation of switch	First activation of switch
	Select	Short activation of switch	Long activation of switch	Second activation of switch
2	Scan	Continuous Scanning for duration of Scan switch activation	Single Scan for each activation of Scan switch	Continuous Scanning toggled on/off by Scan switch activation
	Select	Activation of Select switch for both 2 and 3 switch input		
3	Scan	Same as 2 switch input except that "Device Lists" and "Labels" are Scanned independently using 2 different Scan switches		

LIGHTS AND APPLIANCES

In addition to home entertainment devices the Home Entertainment Plus is capable of controlling up to 16 lights or appliances. X-10 Homecontrols Inc. manufactures power control modules which control lamps and appliances over the existing house wiring. The Home Entertainment Plus's X-10 functions are controlled via the OneForAll Command Center. When the user selects a "Label" to control lights or appliances, the Home Entertainment Plus transmits infrared information to the OneForAll Command Center. This infrared information identifies which of the possible 16 X-10 modules to control and whether the desired function is ON, OFF, or DIM (lamp modules only).

UPGRADABILITY

Presently, the Home Entertainment Plus will work with most brands of home entertainment equipment. As new devices are added to the library of codes, the new codes for these devices may be downloaded to the Home Entertainment Plus.

POWER SUPPLY / BATTERY BACK-UP

The Home Entertainment Plus may be powered by either an internal gel-cell rechargeable battery, the powered wheelchair battery, or a CSA/UL approved AC power adapter. All system lists and operational parameters configured by the user are maintained in the battery backed-up RAM powered by its own lithium battery. During periods of inactivity the Home Entertainment Plus is automatically placed in sleep mode to conserve power. The length of time the unit can operate from a single charge of the internal gel-cell battery is dependant on several factors, but the device should operate for several days under normal use.

CONCLUSION

The Home Entertainment Plus represents a valuable solution for the independent control of home entertainment devices, lights, and appliances when fully integrated environmental control system are not required. It is anticipated that the Home Entertainment Plus will have a significant positive impact on the quality of life for those individuals living independently in the community.

ACKNOWLEDGEMENT

The authors wish to thank the Bloorview Foundation for their continuing support of the Responsive Development Team.

For further information contact:
Mr Larry Silver
Design Technologist
Bloorview Childrens Hospital
25 Buchan Court
Willowdale, Ontario, M2J 4S9
CANADA

Single switch direct manipulation

Andrew J. Moynahan, Richard M. Mahoney
Applied Science and Engineering Laboratories (ASEL)
University of Delaware/Alfred I. duPont Institute
Wilmington, Delaware USA

ABSTRACT

The design of the interface for single switch direct manipulation is discussed. Limitations of current methods are examined and criteria for the design of more functional systems are proposed. An alternative approach is introduced that relies on an intelligent planner to propose movements that may be accepted or rejected by a user. A cursor control demonstration of the approach is discussed.

INTRODUCTION

Humans perform many tasks through both physical and abstract direct manipulation. In the physical world, the arm manipulates the hand from location to location, facilitating the transportation of objects (like lifting a coffee mug to the mouth) or the completion of activities (like flicking a light switch). In graphical computer interfaces, an input device (the mouse or similar) is used to manipulate the screen cursor (an abstract hand) from location to location, facilitating the transportation of graphical objects (like moving an old file icon to the garbage can icon) or the completion of activities (like selecting an application icon through a double click).

A range of physical disabilities exist that impair people's ability to perform direct manipulation tasks, both physical and abstract. Software options have been developed that enable direct manipulation in a graphical user interface [1,2] for people with a wide range of disabilities. Researchers have investigated the use of robotics as one option for augmenting physical manipulation. Leifer [3] has highlighted analogies between the human-computer interface and the human-robot interface.

Current direct manipulation implementations for people whose primary interface is a single switch are inadequate to provide access to all of the benefits of direct manipulation. This paper discusses some limitations of these solutions and puts forth a set of criteria that are intended to guide the development of better solutions. An alternate solution approach is proposed and a cursor control demonstration program is discussed.

BACKGROUND

The standard approach for providing single switch direct manipulation is to introduce an intermediate level of interaction that interprets switch inputs into movement commands. The user interacts with the switch to select a movement direction from a scanning interface and again to cause the movement to occur. Movements are constrained to move at either a constant velocity or constant acceleration. Figure 1 is a flow diagram that describes the steps that must be performed to carry out a task using this design for single switch direct manipulation. The number of steps the user must take between the initiation of a manipulation intention and its completion is substantial. A great deal of attention is demanded of the operator to generate the mental plan, interact with the interface to select the desired directions, generate the control signals to drive the movements, and to monitor the movement. The burden of controlling the direction of movement to reach a desired target is placed on the user. Although this approach provides access to direct manipulation interfaces, it does so in a way that reduces the advantages of direct manipulation.

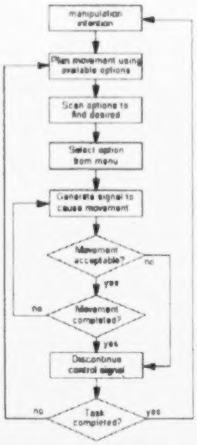

manipulation intention
Plan movement using available options
Scan options to find desired
Select option from menu
Generate signal to cause movement
Movement acceptable?
no
yes
no
Movement completed?
yes
Discontinue control signal
no
Task completed?
yes

Figure 1: Interaction requirements for a scanning based single switch direct manipulation interface.

Several commercial software programs are available to provide access to cursor control in graphical computer interfaces. These systems use scanning to select the cursor direction and focus on allowing undirected movement around the screen. Ke:nx [4], Revolving Doors [5], and SwitchMouse (soon to be released by OMS Development of Wilmette, IL) provide the user with the ability to select incremental and/or continuous changes in the cursor direction using the basic technique described above.

STATEMENT OF THE PROBLEM

The following criteria have been established as guidelines for the design of a control scenario that closely resembles unimpaired direct manipulation performance.

- The control structure should be natural, allowing the user to focus on the task, not on the requirements for accessing movement.
- The interaction between the user and the interface should be flowing and rhythmic.
- Spoken commands are not considered to be desirable. Direct manipulation is powerful because the user becomes physically immersed in the task activity.
- The interface should exploit information about the environment, as has been suggested in [6].
- The resulting motion should be within a range of accelerations and velocities that are similar to those exhibited by human target-directed movements.
- Movements should not occur unless a positive, intentional signal is being generated by the user.
- No visual reference of movement directions should be required.

The ultimate goal is to provide a manipulation tool that mimics the efficiency with which the human motor system generates motor control signals for manipulation. Further discussion of these criteria and the solution proposed below may be found in [7].

SOLUTION APPROACH

Many research issues exist in order to create a direct manipulation access solution that meets the above criteria. An approach is being investigated which augments the control process of the user by introducing an intelligent planner. The role of the planner is to predict the desired movement intention of the user. The user interacts with the planner through switch presses that provide information and cues for updating the planner's predictions. Figure 2 describes a possible interaction of the user switch presses with the planner. All planning is done by the planner and the user either agrees or disagrees with the motion.

The success of the planner is measured in terms of its ability to accurately predict the user's manipulation intentions. Constraints on the task and movement environment provide a basis on which a well-designed planner may postulate desired motion. The goal of this method is to create a natural control approach that activates movements through physical signals that do not require a scanned menu list. Target-directed movements are generated through a simple go/no-go approach.

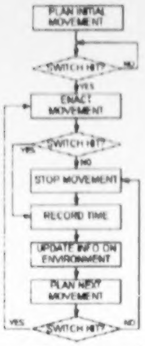


Figure 2: Proposed user switch interaction with the movement predictor/planner.

The direct manipulation approach outlined here is fundamentally based on two assumptions, 1) user manipulation intentions are target-directed, and 2) an intelligent planner can be designed to predict user target-directed manipulation intentions.

If the prediction of the planner is correct, the movement would be in a way that is expected by the user. The switch would continue to be pressed as long as the movements reflected the intentions of the user. If the movement is not what is desired, the user immediately releases the switch and all movement ceases. If a correct movement sequence is generated by the planner, the user continues to hold the switch as long as the movement matches the user's task goals. A delayed release of the switch may be interpreted by the planner to mean that the initial part of the manipulation plan, up to the release of the switch, was correct, but that some different plan is then desired.

Other information is available to aid the planner in creating its motion prediction. This information may include the history of switch presses, knowledge of objects in the environment, knowledge of the environment structure, and movement constraints.

OVERVIEW OF SYSTEM

A demonstration of this approach has been developed for controlling the screen cursor in a standard Microsoft Windows GUI. This interface consists of a single switch and the motion planning software. The single switch currently used for the system is the right mouse button, which was chosen only for convenience. The actual movement of the mouse is controlled by the software. The user is responsible for starting and stopping the movement of the mouse cursor. This is done with the single switch. When the user holds down the right mouse button, the program selects an object from its list of potential targets and begins moving the cursor towards the chosen target.

BEST COPY AVAILABLE

cursor position to the target position. If the first target selected by the program is not the target desired by the user, she/he would then release the mouse button and then depress it again.

Releasing the button provides the program with information. The approach may be further clarified through the example diagrammed in Figure 3. The location of the cursor with respect to an icon may provide an indication to the planner of the user's movement intention. If the planner begins along the solid path, but the user releases the switch at point A, the planner may infer that the user intended to move towards the **calculator** icon. Upon pressing the switch again, the cursor would then move in the direction of the **calculator** icon. A similar inference may be drawn for the **control panel** if the user had released the switch at point B. By not releasing the switch, the planner would have continued to move the cursor in the direction of the **notepad**.

The mouse emulation software was written as a stand alone Windows application. It was written in C and compiled with the Symantec C\C++ compiler. The program installs a mouse hook to trap mouse events when the program does not have input focus. Trapping mouse events is important since the single switch used in this system is the right mouse button.

User trials are currently being planned to test user acceptance of this approach. Baseline comparisons will be made to other scanning based cursor control techniques.

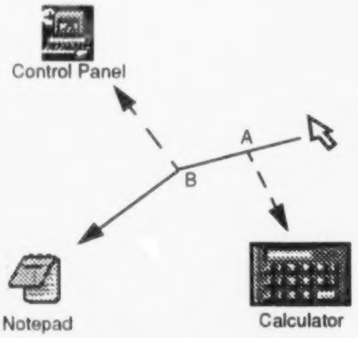


Figure 3: A possible sequence of movements depending on the user switch interaction.

DISCUSSION

The planner in the demonstration program does not currently make extensive use of environmental information; it simply moves along a list of icon locations. The nature of any intelligence is a basic research question still under review. Another possible addition to the system is a feature to alter the trajectory of the cursor movement. Currently, the cursor moves at a constant velocity. A typical user, however, does not move a mouse at a constant velocity when moving towards a target. There are periods of accelerating and decelerating throughout the entire movement. If the target is known, this type of motion is possible. This approach is currently proposed only for target-directed movements. Further work is required to specify an approach that will meet the design criteria for free movement.

Finally, the program described above is also being used as a test-bed for future application of this direct manipulation approach to the control of a assistive robot.

REFERENCES

1. Brownlow, N., Shein, F., Thomas, M., Milner, M., Parnes, P., *Direct Manipulation: Its Significance For People With Disabilities*, Proceedings RESNA 12th. Annual Conference, June, 1989, 244 -245.
2. Brownlow, N., Shein, F., Thomas, M., Milner, M., Parnes, P., *Direct Manipulation: Problems With Pointing Devices*, Proceedings RESNA 12th. Annual Conference, June, 1989, 246 -247.
3. Leifer, L., *RUI: Factoring The Robot User Interface*, Proceedings RESNA 15th. Annual Conference, June, 1992 580-583.
4. Ke:nx is a trademark of Don Johnston Developmental Equipment Inc.
5. Lewis, J., Marsden, R,. *Cusor Sequencing For Single Switch Access On The Macintosh*, Proceedings RESNA 16th. Annual Conference, June, 1993, 464 - 466.
6. Brownlow, N., Shein, F., Treviranus, J., Milner, M., Parnes, P., *Don't Manipulate, Delegate!*, Proceedings RESNA 13th. Annual Conference, June, 1990, 153-154.
7. Mahoney, R.M. (1993). *Human Target-Directed Position Control*. Unpublished Ph.D. Dissertation, Department of Engineering, University of Cambridge, Cambridge, England.

ACKNOWLEDGMENTS

This research is supported by the U.S. Department of Education, Grant #'s H129E20006 from the Rehabilitation Services Administration and H133E30013, the Rehabilitation Engineering Research Center on Rehabilitation Robotics, from the National Institute on Disability and Rehabilitation Research (NIDRR). Additional support is provided by Nemours Research Programs.

Andrew Moynahan
Applied Science and Engineering Laboratories
A.I. duPont Institute
1600 Rockland Road, P.O. Box 269
Wilmington, DE 19899 USA
Internet: moynahan@asel.udel.edu

Virtual Interaction; An Interface for Individuals with Disabilities

Arthur W. Joyce, III, Ph.D.; Anna Phalangas, B.S.
Applied Science and Engineering Laboratories,
University of Delaware / Alfred I. DuPont Institute

Abstract

Virtual interaction merges a video image of a user with computer generated graphics. Interactions produce the illusion that the graphical objects are real, tangible objects which can respond to and be manipulated by the user. A low immersion virtual reality system has been developed to provide an interactive play environment for children with disabilities. This virtual interaction environment can provide individuals access to new experiences and can be tailored to adapt to their cognitive and physical abilities. It can be used as a motivational tool for education and therapy.

Early evaluations indicate that this interaction method is promising. However, more research needs to be done to explore potential applications and determine the limitations of this technology.

Background

Virtual interaction uses low-immersion virtual reality technology as a human-computer interface. It has the benefits of virtual reality, providing experiences which are not otherwise possible, while not requiring the cumbersome and expensive equipment of high immersion virtual worlds.

The envisioned application for the system is a motivational, virtual play environment for education, therapy and rehabilitation. It was designed primarily with off-the-shelf components to insure that it would be affordable for schools, hospitals, and therapy facilities.

The output of the system consists of the live video images of people merged with computer generated objects projected onto a large screen. The graphical objects interact with the users' images, in real time, in a manner which produces the illusion that they are tangible and can be manipulated in different ways by the users.

The inspiration for this work came from *Artificial Reality* by Myron Krueger [KRUG90]. In his book, he describes a variety of interactive environments involving audience participation. METAPLAY was one of Krueger's first systems that combined graphics with live video images. The graphics were created by a human artist, who was to hopefully someday be replaced by a computer, and were drawn to appear to respond to the participants' actions. The successor was a creation called VIDEO PLACE. The environment used the silhouettes of the participants to control various computer generated graphical experiences. The users only saw themselves as silhouettes which might be scaled, moved, and distorted. They could engage in a number of physical activities; throw an object, touch another user's silhouette (which caused the system to respond with funny sounds), or even play with a pet "critter" which ran about the silhouette. Another environment, VIDEO DESK, was similar to VIDEO PLACE but only used the silhouettes of the hands of the user for control.

Krueger presents strong arguments for why virtual interaction should be considered for human-computer interaction. He states that, "interaction is a central not peripheral issue in computer science." The visual feedback of his virtual environments encourages interaction. He has observed that when people see themselves, they instinctively want to reach out and touch their images [KRUG85]. When the images respond, the interaction quickly becomes a "rich dialog." Krueger, also notes that it is inherent in human nature to want to "understand, navigate and manipulate the physical world." Therefore, interactive experiences, visualization, and the composed worlds of virtual reality should make effective teaching tools.

It would only seem appropriate to apply this technology to children with disabilities to open new worlds and to offer them ways to interact with apparently physical objects in a non-corporeal way. This could enhance their development by providing them with experiences that would not otherwise be possible given their physical abilities. It could also provide clinicians, and educators with motivational tools to help enhance and reinforce their therapy or education.

System Design

The system is based on an IBM compatible PC. Live video is merged with computer generated graphics. The processing begins with the conversion of the users image to a silhouette. This is currently accomplished by a simple threshold separator which operates on either a luminance or chroma-key signal. This effectively separates the foreground (user) from the background. The software processes the silhouette to determine the interactions between the user and the computer generated environment. Unlike VIDEO

PLACE, the displayed video still contains the original color images of the users.

Two setups exist for the system. The vertical setup places the users in front of a backdrop with the camera next to the display and provides them with their mirrored images. Depending on the amount of movement that is appropriate for the application, the video may capture the users from head to toe, their upper bodies, or just a particular limb. The horizontal setup places the camera above the users with the backdrop essentially across their laps. This setup provides a tabletop interaction space and may more accurately accommodate the needs of specific applications, the capabilities of the individuals and the amount of space available.

The live video image and graphics are merged and displayed with a Creative Labs Video Blaster Card. The card is controlled through the Windows MCI (Media Control Interface) overlay-device facilities. Audio feedback is provided through a Creative Labs Sound Blaster card which is controlled either through the MCI interface (to play digitized sound clips) or through the Windows MIDI control interface (to access the FM synthesizer).

Development

The software has been and is being written in C++ as a series of libraries to allow applications to be developed quickly and easily. It runs under Microsoft Windows. The advantages to this approach are support for multiple vendors' products, portability, and access to graphics libraries. The disadvantages are slow execution and lack of good animation support. Windows lacks double buffering and effective timing control which are needed to prevent visible artifacts caused when the screen refresh occurs during the graphics generation process.

Currently there are several demonstration programs running. Some of the implemented interactions include; simple switches, bouncing, finger tracking, drag and drop, and encirclement. Events may also be linked to audio output.

Bouncing is an interaction between the user and moving graphical objects. The bounce algorithm bases the angle of reflection on the normal of the user's silhouette at the point at which it touched the object.

Tracking allows the user to drag and manipulate graphics. The program locates the sides of the finger and calculates its axis and then finds the finger tip. Two modes of operating the tracking interface are drag and drop, and encirclement. Drag and drop simply waits for the user to hold still and then drops the graphic at the resting location. Encirclement records the traced path and checks whether it has crossed itself.

There are a number of partially developed components that also exist in the series of libraries. A controllable music player allows music compositions or sound effects to be incorporated and synchronized with the interactions. Facilities for animation are being explored to provide more complex movement and interaction models.

Discussion

Some preliminary investigation has been done to identify appropriate applications for users with varying capabilities. While the initial focus was on children with Cerebral Palsy (CP), it is apparent that there were other segments of the population that can benefit from the system. Among these are head injury and burn patients. The investigation involved consumer input, a number of interviews with clinicians and observation of therapy sessions.

It was interesting to see the wide variety of philosophies and approaches that exist today. Whether they were interdisciplinary teams with speech, occupational and physical therapists coordinating their efforts, or isolated, one on one therapy sessions, a common emphasis among all approaches seems to be to find innovative ways to provide motivation.

One demonstration program written for the system is a variation on *Break Out*. This game involves a moving ball and several rows of bricks placed across the top of the screen. When the ball hits a brick, the brick is destroyed and the user scores points. The user must try to keep the ball in play and deflect it toward the remaining bricks with a hand, arm, or other part of the body depending on the set up. Initial reaction to this game indicates the system succeeds in creating the illusion that the ball is real. The users often chuckle when the ball bounces off their heads and duck to get out of its way. When sound is produced at the moment the ball encounters an object, the illusion of physical contact is enhanced even more.

This application could be used for individuals with CP who might require therapy for muscle control and strengthening. It could be adapted to target specific movements. Head trauma patients often need to relearn skills such as eye-hand coordination and this game provides that type of interaction. Burn patients must exercise their limbs in order to prevent fluid build up. However movement can be uncomfortable and touching anything is painful. The game need not require any physical manipulation. It provides motivation for movement and hopefully shifts the users' focus away from the rigors of the physical exercise.

Some other programs have been written to involve activities that focus on cognitive development. One game is designed to stress memory development while another is designed for use in teaching written language skills. A third program uses finger tracking to provide a virtual finger painting environment. One focus of the development has been to incorporate attractive graphical objects and animation in to the applications to make them engaging to children.

Future works

A continuing area of research is the foreground/background separation. The current system works well under controlled lighting. However it is not reasonable to demand this condition in clinical or classroom settings. Also, bright lights are incompatible with the projection TV system used to display the video. Space is also an issue. Krueger was able to dedicate whole rooms to his interactive environments. Providing large backdrops in clinics or classrooms will not be practical. Future research will explore the use of edge-extraction algorithms to determine the boundaries of the silhouettes.

More interaction models will be developed. Gravity, dynamic velocity, sticky objects, and non-elastic bouncing will be incorporated to provide more variety in the authoring environment. Line-smoothing should be added to the tracking interface. The ultimate goal of the software development is an authoring tool kit which should make it reasonably easy to produce new applications.

The threshold is currently calculated on a custom, one-bit video capture card. This card is simple and would not add significantly to the cost of a system. However, if this system were being widely distributed, all functions, including video input, video output, and image processing, could be incorporated in a single card.

User evaluation of the system with the target population has only occurred on a limited demonstration basis. The system has progressed to the point that it can be shown to clinicians. It must be tested with the target populations because it is important to understand how individuals with various cognitive and physical abilities participate in the virtual environments.

The process of creating meaningful interaction environments will further study current techniques in therapy. For example, one technique observed for strengthening trunk control in children with CP makes them lie on their stomachs in a hammock. It is possible to envision the system responding to exercises done in this position to allow the child to control their flight through a virtual world. Other therapy methods might include adapting a game to accompany a weight training regimen. The social dynamic of play should also be studied for this environment.

Conclusions

This system was designed to use play as a motivational activity for children with disabilities. It merges live video with computer generated graphics. It allows the users to activate graphics and create an interaction on the display that appears real. It provides visual and auditory feedback. The system allows the whole body to be used for interaction and can be adapted to the capabilities of an individual user. It has the potential to offer individuals access to new experiences while challenging them to interact in a therapeutic or educational way.

It is clear that the potential audience is quite varied in cognitive and physical abilities. The environment must accommodate the needs of the individual users. Further development will provide more interaction modes. Further research will study the benefits of the interaction.

References

[KRUG85] Krueger, M.W., Gionfriddo, T, & Hinrichsen, K, VIDEOPLACE--An Artificial Reality, CHI '85 Proceedings, p35-40, ACM press, April 1985

[KRUG90] Krueger, M.W., *Artificial Reality II*, Addison-Wesley Publishing Co., 1990

Acknowledgments

This research is supported by the U.S. Department of Education, Grant #'s H129E20006 from the Rehabilitation Services Administration and H133P30003 from the National Institute on Disability and Rehabilitation Research. Additional support is provided by Nemours Research Programs.

Author address

Arthur Joyce, or,
Anna Phalangas
Applied Science and Engineering Laboratories
Alfred I. duPont Institute
1600 Rockland Road
Wilmington, DE 19899
Phone: (302) 651-6830
Email: joyce@asel.udel.edu, or,
phalanga@asel.udel.edu

A COMPUTER LITERACY PROGRAM IN AN ACUTE REHABILITATION SETTING

Patricia Zuba, OTR, Division of Occupational Therapy
Glen Ashlock, M.S., Rehabilitation Engineering Program
University of Michigan Medical Center

Abstract

Computer skills for people with disabilities are useful for daily living activities as well as increasing options for work and continued education. Overall health includes being able to function at maximum potentials.[1] This paper describes a computer literacy program which is a component of an inpatient acute rehabilitation program. It contains the history of the program, its goals, and the methods used to achieve these goals. Two short case studies are included to help illustrate types of clients served by the program.

Background

In 1987 a program was started for spinal cord injury (SCI) rehabilitation inpatients with the intent of increasing their computer knowledge, interest, and access.[2] This program continues as a collaborative effort between the Division of Occupational Therapy and the Rehabilitation Engineering Program. It has evolved due to insights gained while presenting the program and constraints imposed by the changes in the health care system.

In addition to newly injured SCI patients, the program has expanded to include general rehabilitation adult and pediatric patients throughout the medical center. Referrals are initiated by physicians, nurses, therapists, and case managers for patients at all stages of the rehabilitation process.

Objectives

The main objectives of the program are to provide the patients a sufficient knowledge base to determine if computers will be a useful tool and how to continue their learning if desired and to help overcome a fear of computers when needed. We try to meet these objectives by introducing rehabilitation patients to microcomputers and demonstrating potential advantages of computer usage in their daily living activities.

Methods

The computer literacy program includes assessing patients' needs and abilities and determining the most efficient computer access interface for them. Information and assistance that facilitate the patient in making informed choices about platforms and applications are presented early in the program. Where needed, we work with the client to make specific equipment recommendations. Based on the patient's functional abilities, impairments, and identified needs, justification for obtaining funding for this equipment is provided by the medical team.

The program is divided into a series of learning modules. Each module has an outline of material that should be included for basic and advanced level training. These modules serve as a guide to explain the program to patients and provide a framework for the training process. However, the specific modules presented, and their order, varies with individual client's needs.

The program begins with a standardized introductory module. This includes a discussion of the types of personal computers and their potential uses, an overview of terminology and hardware components, a demonstration of sample applications, and the opportunity for clients to ask questions. Whenever possible, the introduction takes place in a group setting where participants with varying levels of computer knowledge and social skills can support each other with their different interactive styles. Those without computer knowledge often have a difficult time knowing what questions to ask and may benefit from the questions asked by more experienced or outgoing participants.

The next phase is a needs assessment module, an individual session during which the patient's needs are discussed and evaluated. Areas that are considered include functional communication and potential vocational, avocational, and home management usage. Because many clients have no computer experience, they often require a great deal of assistance visualizing how using a computer can help them in their daily lives, as well as how they might be able to access the computer given their disability characteristics.

As part of the needs assessment, the patient's particular abilities are evaluated to determine the most appropriate means of access. Areas to be addressed in this module include cognition, physical capabilities, endurance and sitting tolerance. The type of computer and programs that will be used are also considered when determining an access method. Several access methods may be demonstrated, and the client has the opportunity to try as many as needed to select the most appropriate methods. The access method that is initially selected may change as the client's abilities change.

In the next sessions, we typically move to the types of operating systems that are available (Macintosh, Windows, DOS). Some patients look at multiple operating systems before deciding on one. Increasingly, clients start the program with a preference for a particular system based on previous use at home, work, or school, or because they have a family member or friend who is knowledgeable about a given system and will be able to provide assistance.

We have found that most people don't want to spend a lot of time focusing on system operation. Consequently, learning specifics about the system operation does not take place in contiguous sessions before moving on to other topics. Many patients have expressed that they are not "doing anything useful" by just learning the system; they want to move on to what they perceive as more purposeful applications. Once they gain a better understanding of how they will be using the computer, it is easier for them to relate to learning about the operating system.

The sample applications module allows the patient to learn about applications he or she may be interested in using, such as word processing, spread sheets, or games. The goals and previous level of computer knowledge of a particular client determine whether he or she is exposed to a variety of applications or concentrates on specific applications that may be needed for work or school. To maintain interest and to demonstrate the practical uses of computers, we focus the training on projects which are meaningful to the patients. For example, the introduction to learning the word processor may take the form of writing a letter to a friend or a request for information.

Toward the end of the program, purchase of a system for home, work, or school is discussed. If a client has identified a need for a system and has participated in the program sufficiently to demonstrate they are motivated and will make use of the system, a letter of need is written. The client and rehabilitation engineer work together to decide which system components will be needed, making sure that the client can validate the need for each component. This letter, signed by the physician, occupational therapist, and rehabilitation engineer, specifies the components needed and includes the medical and functional justifications. The recommendations provided can be useful in obtaining funding from insurance, state vocational agencies, or other sources.

The introduction, needs assessment, and the special inputs evaluations are typically conducted jointly by Occupational Therapy and Rehabilitation Engineering. The remainder of the training is provided by Rehabilitation Engineering, allowing patients to work on other rehabilitation goals in occupational therapy. While sessions may be conducted separately, close communication between the disciplines is maintained. The program is considered a part of the total rehabilitation process and is therefore billed the same as other in-patient therapies. If the patient wishes to continue the program after discharge, a funding source must provide prior authorization.

Results

As part of the Model Spinal Cord Injury Care System study, some participants in the literacy program completed questionnaires prior to discharge. These patients represent only a fraction of those who have participated in the program. The results from these questionnaires reflect trends that have been observed through anecdotal evidence.

The most consistent difficulty with the program, as identified by the patients and clinicians, has been a lack of time in which to participate in the program. Time conflicts with other therapies and starting the program too late in the rehabilitation stay were frequently stated as causes. This is largely due to shorter lengths of stay and increased patient acuity, combined with an increase in the number of therapies throughout the day such as therapeutic recreation and independent living classes. These issues have led to increased requests for computer training services on an outpatient basis.

Since the program started, the number of patients who recognize the need for computer knowledge and have expressed interest in entering the program continues to increase. When the authors first became involved in the program, two groups of people were most interested in the participating. One group was those with specific goals for computer use, such as returning to school or work. The other group consisted of people whose disability characteristics, such as high-level tetraplegia, made using a computer important for increased independence in daily living activities. Increasingly, people of all ages, backgrounds, and disabilities are benefiting from the program.

Another trend is the increasing number of patients with previous computer experience. For these patients, the focus is on learning the advanced features that will allow them to make better use of the applications they use most frequently. Shortcuts such as the macro and template features included in their word processor may allow them to reduce the time needed for inputting text while increasing their output. When patients already know the types of tasks they will be using the computer for, it is easier to tailor an access method to meet their needs. The experienced computer user can, for example, learn more about creating voice macros or customizing a scan tree. This allows them to independently explore and efficiently use new applications. The emphasis of tailoring the program to each patient's specific needs has allowed us to smoothly adapt to these trends.

The following case studies help to illustrate some of the types of clients the program serves and how different outcomes can be considered successful.

SB is a 29-year-old man who worked as a commercial pilot. He was involved in a work-related accident which resulted in blindness, a below-knee amputation, and other injuries. He had only minimal exposure to computers prior to his accident but enjoyed exploring new technologies. He started the program during his inpatient stay and continued as an outpatient.

He learned the keyboard in occupational therapy before starting the literacy program. With the use of a screenreader, voice synthesizer, and scanner, he became very proficient with word processing, spreadsheets, and DOS. He tried several screenreaders and applications before making a final choice and was very involved in learning about and specifying each component of his computer recommendation.

The recommended system was approved by his insurance provider, and we are currently awaiting delivery. He recently completed rehabilitation at the state school for the blind and plans on starting graduate school. He feels that the computer is one of his most important tools, as it allows him to independently manage his finances, written communication, and daily schedule. This provides him with the opportunity to pursue educational goals and increase his work options.

BR is a 54-year-old man who sustained a C7 level spinal cord injury as the result of a motor vehicle accident. Prior to his injuries, he was a middle school teacher who had some exposure to computers but did not own or use one on a regular basis. He described himself as being "computer-phobic" He started the program during his inpatient stay primarily because he recognized computer use would be important for his return to work. Once he started, he found he enjoyed the program and continued it throughout his stay. He focused on word processing for creating lesson plans, personal finances, and recreation. Recommendations for a computer system were completed at discharge.

Due to medical and personal reasons, he decided against returning to teaching, so he did not pursue acquiring a computer system. Two years after leaving the hospital, the recommended system was finally purchased by his insurance carrier, at the prompting of his family, to encourage him to become more active and independent. He located a computer tutor through a local adult education program.

BR started using the computer for simple tasks, working only when the tutor was there. Gradually, he started spending more time working independently. He began volunteering twice a week, teaching emotionally and educationally handicapped students. BR now reports using his computer about 50 hours per week for lesson plans, a personal research project, letters, games (both alone and with his family), and a commercial on-line service. He requires some assistance with set-up of the system, but is independent after that.

The first case provides an example where the program had a clear and immediate impact on the client's computer use. Unlike SB, BR's experience with the program was not as direct but may have been as important. Even though he had a tutor from outside of the program and it took several years to return to computers, BR feels the computer literacy program "opened the computer world" for him and that he would not be volunteer teaching and using computers without it.

Discussion

The success of this program suggests that it is useful to incorporate computer literacy training in an acute rehabilitation program. It provides an introduction to functional uses of computers and demonstrates to newly injured patients the potential role computers can have in their continued independence.

The program serves as a basis for continued computer use and education but does not typically provide all the necessary training to be a proficient computer user. The demand for continued training on an outpatient basis continues to increase and more opportunities for this training are necessary. Training for clients with the transportation and funding to pay for continued training is available through our facility and other outpatient programs, but few clients have these resources.

Our experiences suggest this program is having a positive impact, but more objective data are needed to confirm this perspective. We would like to conduct outcome studies to show the usefulness and long-term cost effectiveness of the program. Positive outcome results would be useful in demonstrating to third-party payers the importance of computer access for people with disabilities. Study results would also help us monitor the results to ensure the program continues to meet the challenges presented as our clients' needs and the health care system evolve.

References

1. S Merrow, & C Corbett:, Adaptive computing for people with disabilities, *Computers in Nursing*, pp 201-209, July/August 1994.

2. B Myers, H Horstmann, R Kett, & D Koester: Computer Literacy Training for Rehabilitation Patients, *RESNA Annual Conference Proceedings*, Montreal, pp 422, 423, June 1988.

Address

Patricia Zuba, OTR
Division of Occupational Therapy
University of Michigan Medical Center
Ann Arbor, MI 48109-0046
(313) 936 7170

INTERFACE DESIGN FOR DISABLED USERS: ELICITING USER-CENTERED CONSTRAINTS

D. Akoumianakis and C. Stephanidis
Institute of Computer Science, Foundation for Research and Technology - Hellas (FORTH),
Science and Technology Park of Crete, Heraklion, Crete, GREECE

ABSTRACT

This paper describes the development and application of a technique for eliciting user interface design constraints related to the characteristics and abilities of disabled computer users. The technique constitutes a representation language, for describing human communicative resources and automatically determining syntactic and lexical issues pertaining to the design of the user interface of an interactive application. The technique assumes the existence of a high level user interface tool, currently under development, for realising the proposed syntactic and lexical user interface design.

BACKGROUND

In the past, there have been a number of attempts aiming to apply Expert Systems technologies and Artificial Intelligence techniques to consolidate and model the semantics of selecting appropriate computer access technology for disabled and elderly people (2). These efforts have been hindered by the lack of a universally acceptable assessment protocol defining the impairments in sufficient detail and accurately keeping up with the features of all relevant products. Lack of any meaningful data depicting human performance analysis and human factors studies for disabled computer users hinders any effort to arrive at a comprehensive assessment framework. The reason is the underlying technology-driven approach which characterises the majority of existing manuals. More specifically, a close investigation into some of the existing manuals reveals that a large part of any assessment is predominated by criteria which are posteriory conditions for accessibility. This is to say that such criteria exist only as a result of state of the art in technology rather than due to a comprehensive assessment of human communicative resources. For instance, in order to decide on the ability of a user to operate a Braille device, existing assessment protocols typically assess the ability of the client to read Braille and/or the sufficiency of his/her tactile discrimination. However, these criteria can be hardly taken as objective measures of someone's tactile interaction ability. It follows therefore, that instead of trying to analyse human communicative resources and subsequently determine desirable technology characteristics, researchers have, until now, concentrated mainly on analysing the basic requirements of technological solutions and then map these requirements on to human resources. It is therefore evident that the application of such criteria during assessment, result in comparisons of the human capabilities against a specific technology, thus probably failing to provide an objective account of the available human communicative resources.

STATEMENT OF THE PROBLEM

Given the limited number of devices covered in existing assessment protocols and the lack of meaningful data to facilitate rational selection of optimal device configurations, the design of interfaces for disabled users is still non-systematic, costly and time consuming. Consequently, much still depends on intuition, as existing user interface development environments have not, as yet, succeeded to support *adaptability* during user interface design (4). On the other hand, systems such as that reported in (2), aiming to suggest computer adaptations for disabled users, can hardly be integrated in a user interface development environment facilitating *unified access* and *user-adaptable* interface design (4).

RATIONALE

The present work constitutes an effort towards the development of user interface software tools facilitating *unified access* to interactive computer applications. Recently, the principle of integrating more than one type of user (i.e. blind and sighted) in a high level user interface tool, has been demonstrated in the HOMER UIMS (5). Clearly, software tools which support the notion of *unified access* to interactive computer applications are today one visible and forthcoming solution to the problems of accessibility for disabled users.

DESIGN OF UML

The methodological approach which has been adopted in our research work has not endeavoured to develop yet another assessment manual, or to design a system based on one of the available ones. Instead, our efforts have concentrated in the direction of developing a semantically expressive, flexible and expandable representation language for describing human characteristics of disabled computer users. This language, called ***U***ser ***M***odelling ***L***anguage (UML), is built as an abstraction of existing assessment manuals to provide a mechanism for eliciting and representing user-oriented interface design constraints. This is to say that UML has been constructed in such a way that it can accommodate any one of the existing protocols that a design team may wish to follow, as well as new ones, by simply modifying the language's constant values.

The design of UML encompasses a number of distinctive features and properties that render it expressive, flexible and expandable. These properties can be summarised as follows:

- UML follows the *logic-based* representation paradigm incorporating an *extentional* scheme and an *intentional* scheme. The latter component provides the inferential facilities required to derive knowledge from the current *extension*.
- It is function-free and range-restricted (i.e. all variables draw their values from finite domain sets).
- UML has a finite set of constant symbols.

The above properties qualify UML as a range restricted deductive database.

DEVELOPMENT

UML consists of a set of sections and a set of parameters. Each is composed of the basic and more complex elements of the ESTA language, which has provided the prototyping platform for the current version of UML (3). Sections constitute the inferential facilities provided by UML. Parameters are like variables which determine the flow of control between the sections. A parameter can be one of the following four types: boolean, text, number or category. Any parameter can obtain a value either through a question or through deduction from rules.

EVALUATION OF UML

To test the expressive power and representational sufficiency of UML, an existing assessment manual (1) has been implemented using this technique. The target of the exercise was to determine syntactic and lexical user interface adaptability rules for two interactive application domains, namely the development of communication aids for the speech/motor and language/cognitive impaired users and to facilitate access to an educational hypermedia application for blind users. Part of the range of adaptations considered are depicted in Table 1. Moreover, the logic determining appropriate adaptability rules follows the rule-based protocol suggested by the implemented assessment manual.

Table 1: Adaptation supported

Lexical adaptation	**Syntactic adaptation**
Mini / Expanded Keyboard	Adjustment of Auto-repeat
Keypad Mouse	Sticky Keys Adaptation
Eye Gaze System	Scanning input
Braille	Macro key program
Speech synthesiser	Abbreviation expansion
Morse Code Input System	Word prediction
3 Switch Morse Code, etc.	Delayed Acceptance

Some of the UML parameters which determine the adaptability scenarios are summarised in Table 2. The predicates *bprm* and *vprm* represent boolean parameters and attribute-value pairs, respectively.

Table 2: Example UML parameters

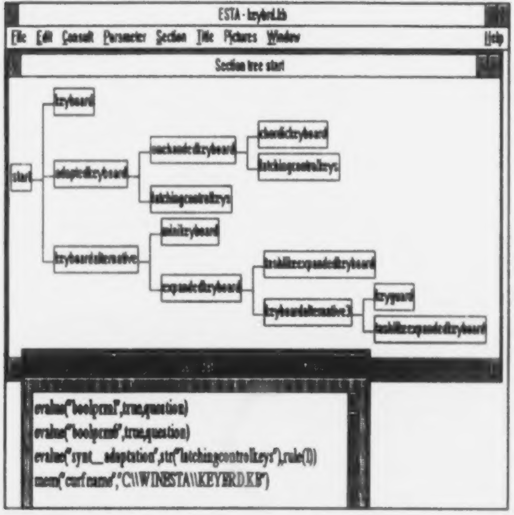
```
bprm(p1"Ability to reach all keys of standard keyboard")
bprm(p2,"Ability to press more than one key at a time")
bprm(p3,"Frequent accidental keystrokes")
bprm(p4,"Ability to strike a single key on demand")
bprm(p5,"Ability to release accidentally struck keys quickly")
bprm(p6,"Frequent multiple keystrokes")
bprm(p7,"Ability to use standard mouse")
bprm(p8,"Key bouncing"
bprm(p9,"Benefit from automated computer functions")
bprm(p10,"Ability to remember sequences of codes")
bprm(p11,"Ability to reach all keys on a mini keyboard")
bprm(p12,"Ability to strike small keys")
bprm(p13,"Ability to reach all keys on expanded keyboard")
bprm(p14,"Ability to strike larger keys")
bprm(p15,"Ability to respond in times patterns")
bprm(p16,"Ability to use three switches")
vprm(p17,"Partial hearing loss or reduced acuity")
vprm(p18,"Total hearing loss or noisy environment")
vprm(p19,"Consistent eye control")
vprm(p20,"Ability for encoded entry")
vprm(p24,"Ability to read braille")
```

Consider, for instance, the selection of a keyboard-like input device. The UML representation of keyboard device selection is depicted in the diagram of Figure 1 (tree-like representation in upper part). The relevant subset of the UML parameters which are used to determine the choice of keyboard are :

p1: User can type on normal size keyboard.
p2: User can strike small keys.
p3: User can reach all keys of mini-keyboard.
p4: User can strike large keys.

p5: User can reach all keys of an expanded keyboard.
p6: User has use of all fingers on both hands.
p7: User has full control of one hand.
p8: User is right-handed.
p9: User insert fingers in holes of keyguard.
p10:User can use ordinary keyboard with keyguard.

Figure 1: Overview of the keyboard device selection



```
evalue("boolpcml",true,question)
evalue("boolpcm6",true,question)
evalue("synt_adaptation",str("latchingcontrolkeys"),rule(1))
mem("curfname","C:\\WINESTA\\KEYBRD.KB")
```

A prototype question-answering system has been developed which utilises the previously described UML structure and a set of rules, to interactively construct user interface design constraints by setting the value of each one of these parameters. At the end of the session, the system has constructed a user model (see lower part of Figure 1), which is a set of user-centered interface design constraints. This user model is subsequently run against a rules file, which is editable by the designer, to infer the valid syntactic and lexical adaptability rules.

DISCUSSION

UML has been developed to provide a representation language which allows the interface design team to elicit user-centred interface design constraints and propose plausible adaptability strategies. Preliminary evaluations have indicated that the expressive power of the language, as described above, is sufficient to accommodate the semantics of existing assessment manuals. This enables the language to support a wide range of adaptability rules for a number of lexical attributes of interaction objects, such as *input device*, *input interaction technique*, *output device*, *output interaction technique*, etc. However, there are cases (i.e. certain lexical attributes of interaction objects) whose adaptation cannot be supported by simply considering input/output device selection. For instance, the *topology* (i.e. horizontal or vertical) of a *menu* is independent of the choice of input device. Additionally, the modality (i.e. highlighted or blinking) of the selector in a *scanning technique* is also device independent. This leads to the conclusion that despite the sufficiency of UML to accommodate semantics of existing assessment protocols, it requires enhancements, if it is to support the full range of adaptable constituents of interaction object classes.

REFERENCES

1. Anson, D. *Selecting Appropriate Alternative Computer Access Technology*, University of Washington, 1991.
2. McMillan, W.W., Zeiger, M., Wisniewski L. *A rule-based system that suggests Computer Adaptations for users with special needs*, Proceedings of ASSETS'94, 1994.
3. Prolog Development Center. *Esta: Expert System Shell for Text Animation*, 1993.
4. Stephanidis, C., Savidis, A., Akoumianakis D. *Tools for designing User Interfaces for all*, To appear in Proceedings of the 2nd TIDE Congress, Amsterdam: IOS Press, 1995.
5. Savidis, A., Stephanidis, C. *Developing Dual User Interfaces for Integrating Blind and Sighted Users : The HOMER UIMS*, to appear in Proceedings of CHI'95 Conference on Human Factors in Computing Systems, 1995.

ACKNOWLEDGEMENTS

Part of this work is carried out in the context of the ACCESS project (TP1001) funded by the TIDE Programme of the European Commission.

Dr C. Stephanidis
Institute of Computer Science,
Foundation for Research and Technology - Hellas
Science and Technology Park of Crete,
P.O. Box 1385, GR-71110 Heraklion
Crete, GREECE
Tel: +30-81-391741, Fax: +30-81-391740,
E-mail: cs@ics.forth.gr

DEVELOPMENT OF ORTHOCAD - A CAD/CAM SYSTEM FOR LOWER EXTREMITY ORTHOTICS

James B. Taylor BEng. Richard E. Hannah MSc.
Queen Alexandra Centre for Children's Health
2400 Arbutus Road, Victoria, B. C. Canada V8N 1V7

Abstract

A CAD/CAM System with application to orthotics is under development. This system utilizes a 3-D shape digitizer based on a six-axis transmitter and receiver. Hardware and software have been developed to permit the realtime digitization and display of 3-D limb data directly from the body. This data is then replicated on existing shape carvers and used for the fabrication of conventional orthoses. The goal of the project is to implement a CAD/CAM system for orthotics that reduces costs and delivery time, together with increased accuracy and repeatibility.

Statement of Problem

The ORTHOCAD Project is an attempt to apply CAD/CAM techniques to the fabrication of orthotics. This is seen as a desirable method of overcoming the high cost incurred in the fabrication of custom orthoses.

A CAD/CAM system has been developed based upon "the Bird" 6 axis digitizer (1), which overcomes the major obstacles in constructing models of complex body shapes. These obstacles include: (a) the need to hold the patient in position for measurement. This may require a number of clinicians to restrain movement, which will preclude the use of a line of sight system of digitizing.
(b) The need for a very fast system for shape measurement, as patient is very often moving due to spasticity.
(c) Computer modeling of the spine, pelvis, right and left leg system requires a multi-axis shape modeling program. Most of the CAD/CAM systems commercially available are designed for prosthetics and utilize a single axis.

Shape Measurement System Design

Shape measurement for ORTHOCAD utilizes the "Bird".(1) This is a six axis electromagnetic digitizer consisting of a transmitter, a one inch square receiver and related electronics. The "Bird" electronics transmits one hundred position samples per second via an RS232 link. The location and orientation of the receiver relative to the transmitter is determined to an accuracy of 0.1 inch and 0.5 degrees. Up to thirty receivers can be connected with each transmitter.

The digitizing system consists of a data-glove containing one receiver for shape collection and auxiliary receivers placed at the hips, pelvis and spine to record the orientation of the patients' body. The data-glove can be swept under a restraining hand to collect the full set of surface data. Each data point is collected relative to the axis receivers, thus accounting for body movement during digitizing. The "Bird" signals are not blocked by any nonmetallic object and so full 360 degree information can be gathered from a patient. Software allows transmission of data and operating parameters between the shape modeling computer and the "Bird" control electronics.

This method of digitizing presents a number of challenges. The first problem to be overcome is the random nature of the data collected. This system does not scan the patient in an orderly fashion and so some method for deciding which data points are to be saved and where to save them had to be developed. It was decided to treat the lower torso as four connected cylinders each with their own central axis. Each center axis is determined by the auxiliary receiver units. Data from each leg, the back and the pelvis is stored in its own data structure and combined by the shape modeling software for display. Each cylinder consists of a series of uniform slices along the centre axis and a set of data points (distances radially from the center axis) at a uniform set of angles. As data points are received from the "Bird" they are filtered by software to determine if they are to be saved. Each point saved is displayed on the computer to create a 3D replica of the body shape as the data is collected.

System Development

Initial testing of the digitizing system indicated that the data transmission rate is too slow to allow rapid digitization. In order that the system be able to process data from moving axes and contain points which would possibly be common to three of the axes, a parallel processor data filter system was proposed consisting of an array of interconnected INMOS transputers each

448

acting as a data filter for one joint axis. This new data filter system consists of a stand-alone processor connected between the "Bird" digitizer and the host computer. The host computer controls the digitizing process and displays the results for the user in real time.

The data filter is an array of microprocessors (transputers), one per body axis. Each processor receives data from axis detecting and digitizing receivers and performs all of the calculations necessary to determine which are useful data points and the proper storage location for the data. These points are transmitted to a PC for storage and display. The processors also initializes and controls the "Bird" digitizer array though the master control remains with the host computer. The system is modular. The number of processors in the array depends on the application. Adding a new axis/limb would require connecting one more processor into the array running virtually the same software.

Display Software Development

After completion of the software to digitize and display the collected data in real time, a program was written to take this shape data and allow on-screen editing of single, two and three axis joint systems. Each joint can be rotated in three axes, scaled and translated relative to one another. Work is underway to allow comparisons of shapes in order to evaluate the CAD/CAM approach with respect to the traditional plaster casting method.

Future Work

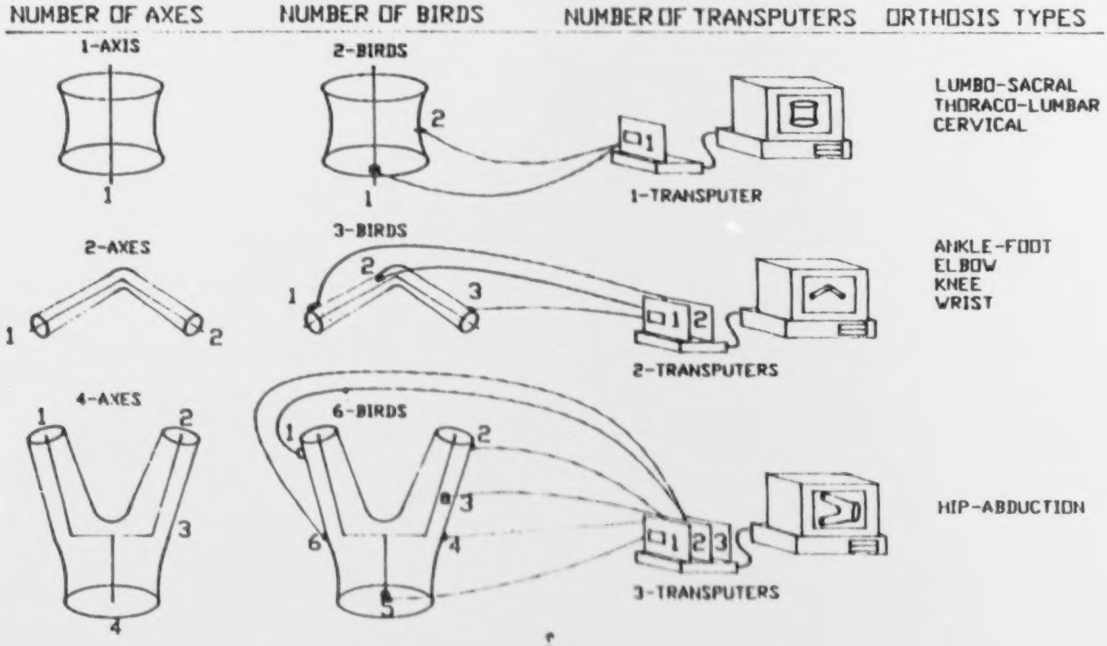
A dual receiver "Bird" digitizer has been purchased and a system for constructing single and dual axes orthoses is under construction. A data glove which will allow the operator tactile sensing as shape data is being collected is also under construction. The near term aim is to build an operational prototype system which can go to clinical trials.

Construction of a four axis carving machine was initiated but put on hold waiting for further funding. Software has been written to allow shape data to be processed by the CANFIT prosthetics CAD/CAM system.(2) This will allow carving of single axis and simple double axis shapes from ORTHOCAD shape data.

Acknowledgements

This work was funded under grants from the Vancouver Foundation and the Science Council of British Columbia.

SHAPE MEASUREMENT SYSTEM



References

1. The "Bird" Position and Orientation System Ascension Technology Corporation. P.O. Box 527 Burlington Vermont U. S. A. 05402.
2. Vorum Research Corporation 8765 Ash Street Suite 6, Vancouver, B.C. Canada V6P 6T3.

James B. Taylor Beng
Fisher Rehabilitation Engineering Building
Queen Alexandra Centre For Children's Health
2400 Arbutus Road, Victoria, B. C. V8N 1V7
phone: (604) 721-6821 fax: (604) 721-6815
email: cjenkins@orca.gov.bc.ca

Proposal for an ECU Standard Protocol

Murray Hensch, B.Sc.E.E., C.E.T.
Kim Adams, M.Sc.E.E.
Madenta Communications Inc. (Edmonton, Canada)

ABSTRACT

This paper discusses a proposed Environmental Control Unit (ECU) standard protocol. This standard protocol defines interconnection specifics, as well as a command set that can be used to control various devices within home and office surroundings. Examples of these various devices are: lights, appliances, and consumer electronics: telephone, TV, VCR, etc. The ability to control these devices is especially applicable for people with physical disabilities.

This protocol can be used by any device that outputs serial data, such as computers and Augmentative and Alternative Communication (AAC) devices. There is assistive technology (AT) available for people with physical disabilities. Using AT, people can control ECU systems through computers and AAC devices.

This paper has been divided into two sections: Section I discusses the proposed protocol; Section II discusses applications associated with the protocol.

BACKGROUND

Technologically advanced devices, providing greater and greater living independence, are being developed for people with physical disabilities. Designers of these devices generally establish a custom protocol for each particular device, which can limit accessibility.

Compatibility with a standard ECU protocol would provide easy and familiar access to ECU's for people who use assistive technology. There are assistive technology solutions associated with the following platforms: Computers (IBM, Apple, Home Built, Other), Personal Digital Assistants (PDA), and AAC Devices.

OBJECTIVE

The protocol being proposed could provide standardization for control of various ECU systems using a variety of computer or AAC platforms. Thus, a standard protocol can provide stability for development of standard control software and hardware. For example, a software developer could design an application that utilizes the standard protocol, with reasonable confidence that hardware developers have created products that the software can readily control.

DISCUSSION

SECTION I

The Protocol Interconnection

A digital communication link is required between the ECU, which is considered a peripheral, and its controlling platform. Computer and PDA controlling platforms tend to have a variety of digital interfaces for communicating with peripherals. Many AAC devices, however, have a single digital communication interface. The common interface tends to be RS-232C. Therefore, the digital communication link associated with the ECU standard protocol is RS-232C.

RS-232C is an established standard that defines electrical and mechanical characteristics associated with the transfer of serial data between data terminal equipment and data communications equipment. The controlling platform is referred to as the data terminal equipment. Peripherals, such as ECU's, are referred to as data communications equipment.

The Protocol Character Code

A set of symbols, known as a character code is required to convey control messages. A standard character code, called ASCII, is commonly supported by computers, PDA's, and AAC devices. Thus, ASCII is the one associated with this proposed ECU standard protocol.

ASCII is a standard, established by the American Standards Committee for Information Interchange, that utilizes blocks of characters to exchange data information. ASCII is a 7 bit code (128 combinations) that defines bit patterns for all the alphanumeric characters, as well as additional control characters.

The Protocol Configuration

The ECU standard protocol has the following data transfer configuration parameters: variable baud-rate, 1 start bit, 8 data bits, 1 stop bit, no parity. The baud-rate can be selected by the ECU designer; 9600 baud is recommended.

Sample Protocol Serial Commands

The serial control command set consists of character packets. The end of a packet is identified using the ASCII carriage return character, <CR>, 0Ch.

Many telephone functions are performed using the de facto standard Hayes Modem AT command set.

```
AT!<CR>
    => flash/link
ATH0<CR>
    => place phone on-hook (hang-up phone)
ATH1<CR>
    => take phone off-hook (pick-up phone)
ATDT x<CR>
    => tone dial number(s) x
```

Additional ECU commands comprise an extended AT command set. An @ symbol is inserted immediately following the letters AT, to indicate the command is not covered by the Hayes command set.

```
AT@HLD=0<CR>
    => deactivate phone hold/mute
AT@HLD=1<CR>
     =>activate phone hold/mute
AT@IRR=x<CR>
    => perform infrared remote command x
    => for example, x could be TV
    => for example, x could be POWER
AT@X10=xy z<CR>
    => perform X10 command indicated by xy z
    => x is HouseCode A to P
    => y is UnitCode 1 to 16
    => z is command
    => for example, AT@X10=A1 ON<CR>
    => for example, AT@X10=H1 OFF<CR>
    => for example, AT@X10=P16 DIM4<CR>
```

The extended AT command set is currently comprised of 22 commands, each with at least 2 variables (1 for enable, 1 for disable). The entire command set deals with ECU status queries, audio gain adjustments, audio switching and routing, data expansion port settings, and intercom switching, in addition to telephone, infrared, and X-10 control.

A bidirectional RS-232C link is required to receive result codes such as OK, ERROR, and RING. The bidirectional link is not necessary, but it allows the controlling device to be more intelligent regarding the results codes sent back from the ECU.

SECTION II

Using Computers for ECU Control

There are many devices on the market which provide alternative access to computers, for example, Ke:nx, Intellikeys, and Voice Navigator. An advantage to using these alternative access methods is that the access method software usually has preferences, for speed etc., which make the overall system more appropriate for the user.

The following list shows some access methods and associated hardware and software for Macintosh®' computers. (R.O.M. stands for range of motion.)

Access Method:	Hardware Reqd:	Software Reqd:
Voice	Voice Navigator	Language Maker or Voice Cmds
Scanning	Ke:nx	Ke:nx Create
Morse Code	Ke:nx	Ke:nx Create
Limited R.O.M	Intellikeys Standard Keybd	Overlay Maker A Macro Maker

The software for these access methods allows you to design layouts to send text or actions to the computer depending on the function the user performs.

The user function to answer the phone could be:

With Voice Navigator, say the words "pick up the phone"

With Ke:nx Scanning, select the icon ☎

With Ke:nx Morse Code, key in the code .._

With the Intellikeys keyboard, press the handset ☎

With a standard keyboard, press the "p"

To have the ECU system actually answer the phone the following chain of events must be executed. The user performs one of the above functions. The access method software interprets the function into a text string. Another software application accepts the text string and determines what serial command to output. These text strings are termed "blind typing" commands.

In the above example, "pickup" is a blind typing command for pick up the phone. The following are more examples of blind typing commands.

For the Phone: hangup<CR>, pickup<CR>, dialone<CR>

For Appliances: X10Command "A1 On"<CR>
X10Command "A1 Dim"<CR>

For Infrared: IRCommand VCR<CR>
IRCommand 1<CR>

Very functional interfaces can be built using a full set of "blind typing" commands. A "shareware" network provides sample layouts to build from. Rehabilitation practitioners are encouraged to donate any overlays designed for specific users.

Using AAC Devices for ECU Control

Many AAC devices have serial ports. Examples of such devices are Liberator, Dynavox, VÖIS, LightTalker, and TouchTalker. The AAC device can be programmed to output the protocol serial commands using its serial port.

The user presses a key combination, then the device sends the serial command to the ECU. Some AAC devices use standards, like Minspeak on the Liberator. Sample icon sequences using Minspeak are as follows.

	First Icon	**Second Icon**
Phone:		
Pick Up	Phone	Thumbs Up
Hang Up	Phone	Thumbs Down
Appliances:		
Lamp On	Sun	Thumbs Up
Lamp Off	Sun	Thumbs Down
IR:		
Power	Entertain	Thumbs Up
Channel Up	Entertain	Thumbs Up
Channel Down	Entertain	Thumbs Down

A "shareware" network also supports the AAC devices.

CONCLUSION

The ECU standard protocol would provide industry uniformity that would be beneficial for both software programmers and hardware designers of ECU systems. The benefits extend to assistive technology users and practitioners. Virtually any alternative computer access and augmentative communication device could access ECU systems using this protocol.

This standard has been proposed as a concept. Response to this proposal, as well as additional input would be appreciated.

TRADEMARKS

Macintosh is a registered trademark of Apple Computers, Inc.; Liberator™, TouchTalker™, and LightTalker™ are trademarks of Prentke Romich Company, Inc.; Dynavox™ is a trademark of Sentient Systems Technology, Inc.; Ke:nx™ is a trademark of Don Johnston Developmental Equipment, Inc.; Intellikeys™ is a trademark of Intellitools, Inc.; Voice Navigator is a trademark of Articulate Systems, Inc.; VÖIS is a trademark of Phonic Ear, Inc.

SECTION I:
Murray Hensch, B.Sc.E.E., C.E.T.
Design Engineer
Madenta Communications Inc.
9411A - 20 Avenue
Edmonton, AB., Canada
T6N 1E5
(403) 450-8926

SECTION II:
Kim Adams, M.Sc.E.E.
Rehabilitation Engineer
Madenta Communications Inc.
9411A - 20 Avenue
Edmonton, AB., Canada
T6N 1E5
(403) 450-8926

ASSISTIVE COMPUTER INTERFACE FOR PEN INPUT BY PERSONS WITH TREMOR

Cameron N. Riviere[1], Nitish V. Thakor[2]
Departments of Mechanical Engineering[1] and Biomedical Engineering[2], Johns Hopkins University
Baltimore, MD U.S.A.

ABSTRACT

A new and simple adaptive algorithm, which can be used as a notch filter, has been developed to suppress pathological tremor during computer pen input. The filter estimates tremor frequency as well as amplitude, adapting the notch frequency to follow frequency modulation of tremor. The algorithm is computationally inexpensive, and therefore suitable for incorporation into pen drivers. It has no phase lag for stationary input. Its performance in filtering handwriting is demonstrated.

BACKGROUND

Pen or stylus input to computers is growing in popularity, as exemplified by the new market in personal digital assistants (PDA's). Handwriting is among the most difficult of activities for many persons with pathological tremor (1,2).

STATEMENT OF THE PROBLEM

An assistive computer interface which suppresses tremor is therefore needed to allow persons with tremor to more effectively use computers with pen input, which is growing in popularity.

RATIONALE

Voluntary motion is very often at a lower frequency than tremor, which is typically within the range 2-12 Hz (2). Hence, low pass filtering has often been used to suppress tremor (3). Many mechanical tremor-suppression devices have a low pass effect (4). This approach is less suitable for pen input, since the frequency content of handwriting ranges as high as 6 Hz (5). A notch filter, which would suppress the tremor frequency while preserving other frequencies, would cause less distortion of the voluntary portion of the signal. The difficulty is that the frequency of the tremor is not known beforehand, and is time-varying, so a fixed notch filter is generally not suitable. We therefore use an adaptive filter, which learns the tremor frequency and amplitude, in order to suppress tremor during computer pen input.

DESIGN

The Fourier Linear Combiner (FLC) (6), also known as the LMS spectrum analyzer (7), is an adaptive method which forms a truncated Fourier series model of a signal. The FLC algorithm is as follows:

$$\hat{x}_{r_k} = \begin{cases} \sin(r\omega k), 1 \le r \le \mathrm{M} \\ \cos((r-\mathrm{M})\omega k), \mathrm{M}+1 \le r \le 2\mathrm{M} \end{cases}$$

$$\hat{\varepsilon}_k = s_k - \hat{\mathbf{w}}_k^{\mathrm{T}} \mathbf{x}_k$$

$$\hat{\mathbf{w}}_{k+1} = \hat{\mathbf{w}}_k + 2\mu \mathbf{x}_k \hat{\varepsilon}_k \qquad (1)$$

where $\hat{\mathbf{w}}_k = [\hat{w}_{1_k} \dots \hat{w}_{2\mathrm{M}_k}]^{\mathrm{T}}$, $\hat{\mathbf{x}}_k = [\hat{x}_{1_k} \dots \hat{x}_{2\mathrm{M}_k}]^{\mathrm{T}}$.

In the FLC, the fundamental frequency is fixed and is considered known. Since tremor frequency is unknown and time-varying, we have developed the Weighted-frequency FLC (WFLC). The WFLC extends the FLC concept by including an additional weight, w_{0k}, which estimates signal frequency. The WFLC therefore can form a truncated Fourier series model for a signal of unknown frequency. The WFLC algorithm is as follows:

$$x_{r_k} = \begin{cases} \sin\left(r \sum_{t=0}^{k} w_{0_t} \right), 1 \le r \le \mathrm{N} \\ \cos\left((r-\mathrm{N}) \sum_{t=0}^{k} w_{0_t} \right), \mathrm{N}+1 \le r \le 2\mathrm{N} \end{cases}$$

$$\varepsilon_k = s_k - \mathbf{w}_k^{\mathrm{T}} \mathbf{x}_k$$

$$w_{0_{k+1}} = w_{0_k} + 2\mu_0 \varepsilon_k \left(\sum_{i=1}^{\mathrm{N}} w_i x_{\mathrm{N}+i} - \sum_{i=1}^{\mathrm{N}} w_{\mathrm{N}+i} x_i \right)$$

$$\mathbf{w}_{k+1} = \mathbf{w}_k + 2\mu_1 \mathbf{x}_k \varepsilon_k, \qquad (2)$$

where $\mathbf{w}_k = [w_{1_k} \dots w_{2\mathrm{N}_k}]^{\mathrm{T}}$, $\mathbf{x}_k = [x_{1_k} \dots x_{2\mathrm{N}_k}]^{\mathrm{T}}$.

When N=1, the WFLC acts as a notch filter. Two channels of filtering are used, for the two (*x* and *y*) components of the input.

DEVELOPMENT

Input to the filter is the offset signal, i.e., the change in position at each step. The best results from the WFLC algorithm are obtained when the mean of the input is zero. Therefore, though it would be possible simply to use the WFLC alone to filter the input, the WFLC is used instead only to estimate the notch frequency by operating on a high-passed signal. An IIR high pass filter with 1.5 Hz cutoff is used. The WFLC (N=1) is used to generate an appropriate reference vector $\mathbf{x}_k$, given the current notch frequency. This $\mathbf{x}_k$ is then fed to a FLC (M=1) which operates on the raw input signal to cancel the tremor. Using this method, for stationary input, the actual signal filtering has no phase lag. The phase response of the IIR prefilter introduces a lag into the frequency estimation, but since the tremor frequency generally changes slowly, the effect on filter performance is small.

Signal frequency components below 2 Hz are assumed to be voluntary. To keep these low frequencies from being affected by the filter, a bias weight (8) is included, which removes the low frequency signal components from the filter error calculation (used to update weight values), but does not subtract them out of the signal. The adaptive gain μ_b governs the bias weight.

EVALUATION

Data to evaluate the method were recorded using a SummaSketch digitizing tablet (Summagraphics Corp., Seymour, CT) with a pen-shaped stylus. The sampling rate was 116 Hz, and the tablet resolution was 0.025 mm. The data presented here were recorded from an undiagnosed female subject (age 87), and a male subject with essential tremor (age 84). Written consent was obtained from each subject.

Figure 1(a) shows a sample of unfiltered pen input. The filtered results are shown in Figure 1 for three different values of the adaptive gain μ. The history of the notch frequency w_{0k} is shown in Figure 1(c). Figures 2 through 5 present more examples of unfiltered and filtered handwriting.

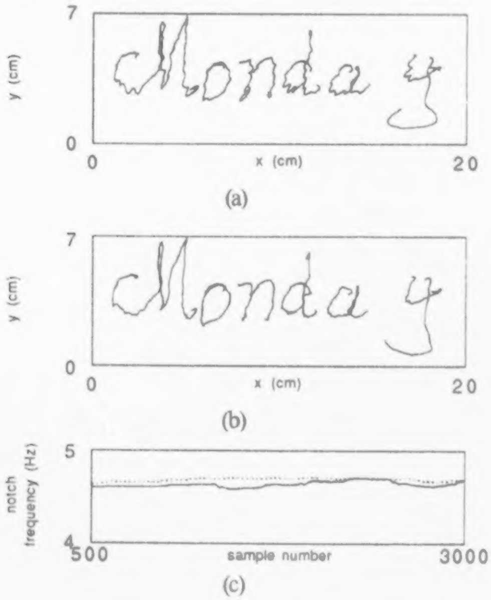


Figure 1. Handwriting sample from male subject, age 84, with essential tremor. μ_1=.005, $\mu_0=2\times10^{-7}$, μ_b=.02, μ=.1. (a) Unfiltered. (b) Filtered. (c) A portion of the notch frequency history. The solid line is the notch frequency for x ; the dotted line is for y.

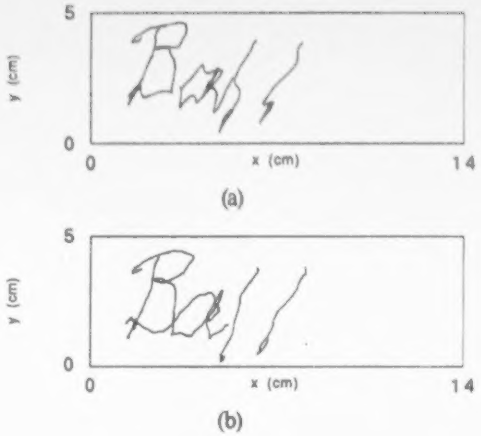


Figure 2. Handwriting sample from male subject, age 84, with essential tremor. μ_1=.005, $\mu_0=2\times10^{-7}$, μ_b=.02, μ=.1. (a) Unfiltered. (b) Filtered.

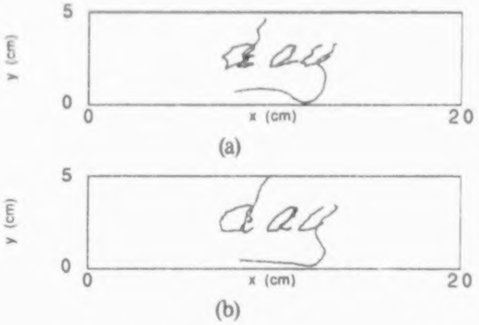


Figure 3. Handwriting sample from male subject, age 84, with essential tremor. μ_1=.005, $\mu_0=2\times10^{-7}$, μ_b=.02, μ=.1. (a) Unfiltered. (b) Filtered.

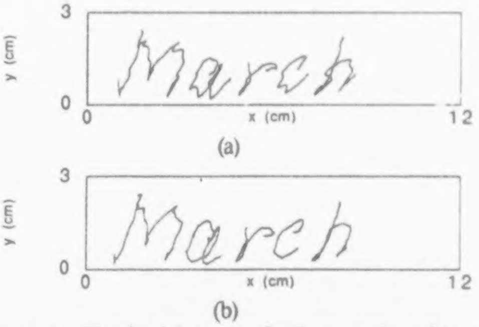


Figure 4. Handwriting sample from male subject, age 84, with essential tremor. μ_1=.005, $\mu_0=2\times10^{-7}$, μ_b=.02, μ=.1. (a) Unfiltered. (b) Filtered.

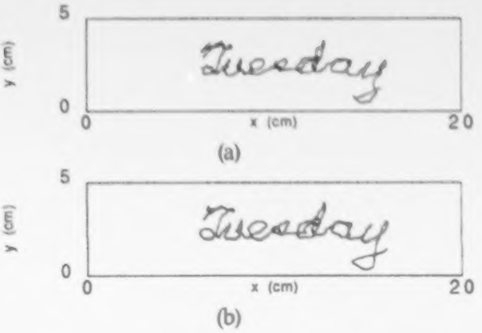


Figure 5. Handwriting sample from undiagnosed female subject, age 87. μ_1=.0045, μ_0=1.6x10-7, μ_b=.02, μ=.1. (a) Unfiltered. (b) Filtered.

DISCUSSION

Adaptive algorithms such as the WFLC are gradient search methods (8), and as such require a certain amount of time to converge to a solution. For this reason, in practical use it would be desirable for a user to write with the pen for perhaps 5 or 10 seconds to allow the WFLC to learn the tremor frequency. After this brief initialization, pen input would function in the standard way. The system's favorable phase response is helpful for PDA's since the pen is also used for target acquisition functions such as choosing icons, in which phase lag can be disconcerting.

The value of μ in the FLC determines the notch width of the filter. This offers a tradeoff. High values of μ provide maximal tremor canceling, but also distort the voluntary signal to some degree. Lower μ values offer the least voluntary signal distortion, with less tremor suppression. A pen driver which included the WFLC notch filter could easily be written with a simple utility to allow the user to choose the value of μ.

Past studies have shown the need that exists for assistive handwriting devices for persons with tremor (1). The WFLC filter presented here filters computer pen input to cancel the effect of tremor during handwriting. This will aid the character-recognition software often used in PDA's. When accompanied by a printer, the method can also be used to generate a hard copy of handwriting input, thereby creating a general assistive handwriting system for persons with tremor. Such a system is currently in development in our laboratory.

The WFLC provides an effective but computationally inexpensive notch filter to suppress tremor during computer pen input. Because of its computational simplicity, it is well-suited to inclusion within pen drivers for PC's and PDA's.

REFERENCES

(1) C. Riviere, N. Thakor and H. Rizer, "Accuracy of upper-extremity motion by healthy and disabled subjects," in *Proceedings of the RESNA 1994 Annual Conference* (Nashville, TN), pp. 170-172, 1994.

(2) R. Elble and W. Koller, *Tremor*. Baltimore: Johns Hopkins, 1990.

(3) P. Riley and M. Rosen, "Evaluating manual control devices for those with tremor disability," *J. Rehabil. Res. Dev.*, vol. 24, pp. 99-110, 1987.

(4) S. Beringhause, M. Rosen and S. Huang, "Evaluation of a damped joystick for people disabled by intention tremor," in *Proceedings of the RESNA 1989 Annual Conference* (New Orleans, LA), pp. 40-41, 1989.

(5) R. Elble, R. Sinha and C. Higgins, "Quantification of tremor with a digitizing tablet," *J. Neurosci. Methods*, vol. 32, pp. 193-198, 1990.

(6) C. Vaz and N. Thakor, "Adaptive Fourier estimation of time-varying evoked potentials," *IEEE Trans. Biomed. Eng.*, vol. 36, pp. 448-455, 1989.

(7) B. Widrow, P. Baudrenghien, M. Vetterli and P. Titchener, "Fundamental relations between the LMS algorithm and the DFT," *IEEE Transactions on Circuits and Systems*, vol. 34, pp. 814-820, 1987.

(8) B. Widrow and S. Stearns, *Adaptive Signal Processing*. Englewood Cliffs, N.J.: Prentice-Hall, 1985.

ACKNOWLEDGMENTS

Funding for this project was provided by the National Institute on Disability and Rehabilitation Research (grant number H133G30064).

Thanks to the test subjects; to Dr. S.G. Reich for providing access to subjects; and to Y. Sun for preparing software.

Cam Riviere
Department of Mechanical Engineering
Johns Hopkins University
Baltimore, MD 21218 USA
(410)516-6570
FAX: (410)516-7254
e-mail: cam@jhuvms.hcf.jhu.edu

SIGN PS: THE DEVELOPMENT OF A SIGN LANGUAGE PRINTING SYSTEM

Alistair Y Cairns, Julian F Cracknell, Peter Gregor, Liesbeth Pyfers, Craig D Ramsay, Ian W Ricketts
MicroCentre, University of Dundee, Dundee, Scotland. DD1 4HN

Abstract

This paper reports on the development of a sign language printing system, Sign PS. It details the reasons why such a system is necessary, and the components of the system, including modules to perform the recognition and representation of sign language. Following this some preliminary results of the recognition system will be presented.

Introduction

The majority of prelingually deaf people have only a limited command of the spoken language(s) of the community in which they live. As a consequence their reading and writing ability of texts in that language is limited as well. Indeed, research in Europe as well as in the USA has proved convincingly that most deaf persons do not reach 'functional literacy', even after many years of special education [1]. Most communication within this group is by means of Sign Languages, but currently there is no conventional written form of these languages. Sign language and signed information are usually recorded using video, photographs, or line drawings. None of these methods provide easy or efficient communication.

The SIGN Printing System that is being developed will allow users to record signs and signed texts efficiently in a standardised and highly readable format, using the computer. The system will consist of a sign font that can be used to represent signs on paper; a sign and document editor; and special purpose sign input devices. A prediction system will be incorporated into the system, to reduce user effort in creating documents, and also to improve the sign recognition accuracy of the system. The system will be supplied with a dictionary of predefined signs, but it will also be possible for the user to edit or create sign representations at will, making the system flexible and sign language independent. Several special purpose sign input devices will be developed.

Sign parameters

Signs are dynamic, three dimensional visual-gestural symbols. Just as words are made up of letters, it is postulated that signs are composed of smaller units [2], for example finger position, hand location and orientation. For the Sign Printing System, the sign parameters that will be used to represent signs are handshape, orientation, location, and movement. These have been further refined to a total of 15 parameters to represent a single hand. Each of these parameters can only take one of a predetermined set of values; for example there are only approximately 56 unique hand shapes in BSL. In addition to these manual parameters, a number of non-manual parameters can be used to further describe a sign. These fall outwith the scope of this project.

Sign font

A symbol set will be developed which will be capable of representing each of the parameter values that may appear in a sign graphically. By combining the representations of each of the parameter values that form a sign, it is possible to create a two dimensional representation of that sign. This symbol set is known as the sign font. In this way, the Sign Printing System should be flexible and extensible, and also reasonably sign language independent.

Sign PS system

The overall system plan of Sign PS is shown below in Figure 1. Sign input in the form of parameter values will be provided by one of several standard and specialised devices, examples of which are shown. These parameters are processed by the Prediction and Completion System, and the output from this is passed to the editing system, ultimately to appear in the form of signs in the document being edited.

Editor systems

There will be two editors with the Sign Printing System. The Sign Editor will be used to compose and edit the graphical representation of a sign based on its individual parameter values. This will involve selecting and grouping the appropriate font elements. The Document Editor will be used to create and edit

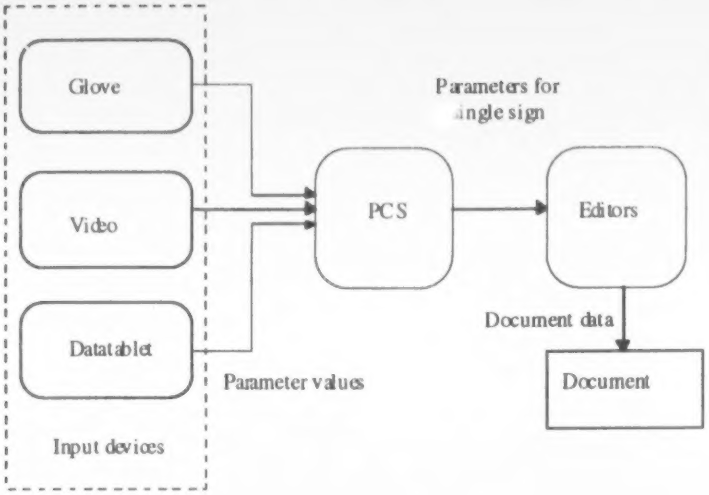


Figure 1

documents which have been written in sign language using the graphical format prepared with the Sign Editor and will provide traditional document processing functions (copy, paste, print, etc.). Standard alphabetic text can also be included in any document.

Sign Input Devices

In order to create documents it is necessary to input signs to the system. To facilitate this, two specialised input methods are being investigated. One method will use a pair of Virtual Technologies CyberGloves which will be worn by the user of the system. As they perform the signs, the changes in location, orientation, shape, etc. of the hands can be monitored and used for recognition by the system. Another method will explore the potential for recognition of sign language using computer vision, i.e. the processing of visual images. Video camera(s) will monitor the subject performing signs to extract a frame by frame description of their actions which can be supplied to the system for recognition. In both cases, the recognition of signs involves extracting the parameter values specified earlier from the signs being performed.

In addition to these specialised input devices, standard input devices such as keyboard and mouse will be investigated. These will also include a data tablet, which will allow the user to enter the parameters for a sign sequentially. These standard input devices will be cheaper and, initially at least, more reliable.

A Sign Prediction system

Prediction and completion systems have been developed for use within conventional alphabetic word processors and in computer based communication systems for severely physically impaired people. They can speed up text input and have been shown to be able to increase not only the quantity, but also the quality of the output [3].

For SIGN PS, a prediction and completion system will be developed that uses the sign parameters as input instead of alphabetic characters: the PCS. As a user provides sign input, the PCS will predict which likely signs are possible, based on the sign parameters, and provide the user with lists of possible signs for selection and hence completion. For the specialised input devices (glove and video) this will add robustness to the system, by filtering 'incorrect' parameters from the input. In the case of the standard input devices (data tablet) this will reduce the effort necessary to input a sign.

User characteristics will be modelled within the PCS system so that sign predictions are provided based upon both frequency of occurrence and recency of usage of signs.

Glove-based sign language recognition

The CyberGlove is an instrumented glove, which records the shape of the hand [4]. It can also provide the position of the hand in three-

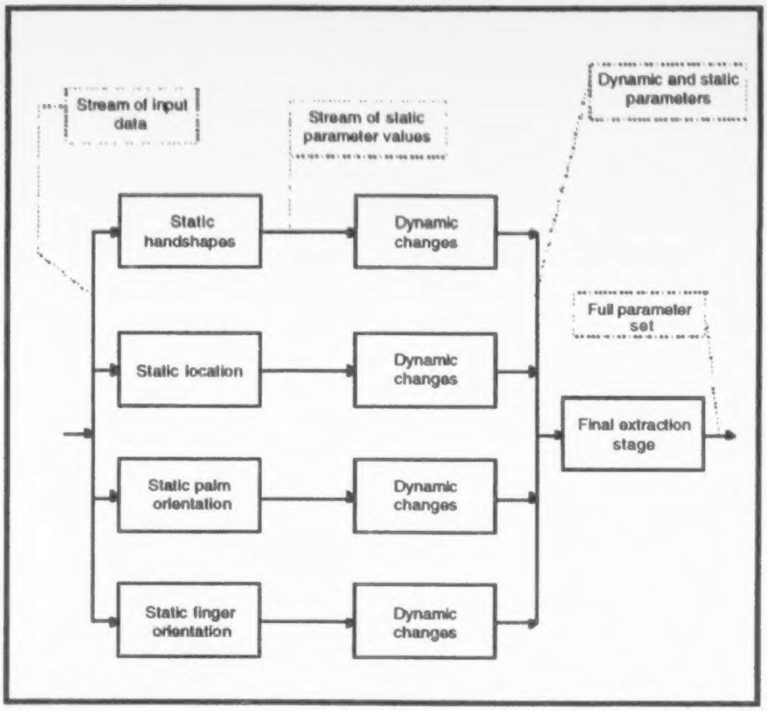


Figure 2

dimensional space, and the orientation. In order for this to be used by the Sign Printing System, it is necessary to turn the raw data into the parameter values specified earlier. These parameters can be divided into two types; static and dynamic. Initially the parameter extraction module will attempt to extract the static parameter values from the input data. A separate module will then attempt to extract the dynamic parameters from this stream of static parameters. This is shown below in Figure 2. Results of the sign recognition work performed so far will be presented at the conference.

Acknowledgements

This work is funded by the CEC under the TIDE program (Project No. TP1202) and is a collaborative venture between 5 European partners: IRV, Hoensbroek, The Netherlands; LTI, Aachen, Germany; The MicroCentre, Dundee, UK; RNR, Amsterdam, The Netherlands; Handicom, Harderwijk, The Netherlands.

References

[1] King and Quigley, (1985) Reading and Deafness. London, Taylor and Francis
[2] Stokoe, (1960) Sign Language Structure: An Outline of the Visual Communication Systems of the American Deaf. Studies in linguistics: occasional papers 8, Buffalo, NY: University of Buffalo. [Rev. edn., Silver Spring, MD: Linstock Press, 1978].
[3] Swiffin, Arnott, Pickering and Newell, (1987) Adaptive and predictive techniques in a communications prosthesis. Augmentative and Alternative Communication 1987, 3(4).
[4] Sturman and Zeltzer, (1994) A Survey of Glove-based Input, IEEE Computer Graphics and Applications, Vol. 14, No. 1, 1994.

Dr. Alistair Y Cairns.
MicroCentre
Department of Maths and Computer Science
The University, Dundee
Scotland. DD1 4HN
email:acairns@mic.dundee.ac.uk

Headpointing: The Latest and Greatest

Kim D. Adams, M.Sc. in EE, Madenta Communications Inc. (Edmonton, Canada)

Brenda D. Bentz, B.Ed., MS, Glenrose Rehabilitation Hospital (Edmonton, Canada)

Abstract

The Macintosh™ with its graphical user interface (GUI) presents a challenge in the provision of assistive technology for computer access. In a GUI environment it is necessary to address not only keyboard access, but, also mouse access. The Headmouse™ is a relativly new device that, with the right software, can provide both keyboard and mouse access. This paper determines the usefulness of the HeadMouse™ for clients with a range of diagnoses. The strategies attempted in the process of using HeadMouse™ with several clients are documented.

Background

Selection of a control technique can affect the extent to which a user can effectively operate assistive technology (AT). User's needs and abilities also dictate the extent to which a user can utilize AT. Some users require minimum access to interact with simple software applications while other users require maximum access to interact with very complex software applications. Clinicians must consider where an individual falls on the "scale of access" to provide appropriate service. The higher one moves on the "scale of access" the more difficult the concepts become, and the greater the cognitive and physical demands.

There are several alternatives available for accessing a Macintosh™ computer. These alternatives include: alternative keyboards, head pointers (mechanical and electrical), mouthsticks, Morse code, and scanning. There are also several tools that can be used in conjunction with the above access methods to make them faster and more accurate. These tools include repeat defeat, sticky keys, slow keys, MouseKeys™ and word prediction.

In many cases, however, the access methods provide users with access that is too slow to be functional. Access speed is important in decreasing order for augmentative communication, computer access, and environment control (except for emergencies) (3).

It is the opinion of the authors that in some cases headpointing can be faster and therefore more efficient than many other access techniques if properly addressed. Headpointing is, at the minimum, faster than scanning (4).

The HeadMouse™ which is a relatively new headpointing device is the focus of this paper. It consists of a small adhesive dot which is placed on the user and a receiving unit connected to the computer. Over the years there have been comparisons of various pointing devices (2,3). The HeadMouse™ lacks research that proves or disproves its potential as an efficient access method.
Upon initial demonstration of HeadMouse™ users are very drawn to the fact that it is simple and unobtrusive, yet provides a high level of independent use. However, upon closer investigation and assessment many users find more difficulties than they originally anticipated because they do not have the required abilities. Individuals with Cerebral Palsy (CP) have difficulty maintaining stable head movements that are necessary to access the on screen targets. Range of motion (ROM) can be a problem for many individuals particularly those with Spinal Cord Injuries (SCI). ROM sufficient to move the cursor to all four corners of the monitor is required.

Individuals with Multiple Sclerosis (MS) may have sufficient physical skills, but, lack the cognitive level necessary to learn concepts such as calibration of the HeadMouse™, Macintosh™ operating system concepts, and use of the software tool Magic Cursor™. Magic Cursor™ does mouse functions in dwell mode or gesture mode (ie. move left for single click). Used in conjunction with HeadMouse™ it provides total Macintosh™ access.

Objectives

To determine the usefulness of the HeadMouse™ for people who do not have all the abilities described above. To document the strategies attempted in the process of using HeadMouse™ with several clients.

Case Studies

The HeadMouse™ was connected to an Apple

Macintosh™ computer. Ke:nx™ and ScreenDoors™ were used for onscreen keyboards and Magic Cursor™ was used for mouse functions. Several users of various diagnoses and levels of ability were assessed on the system. The following is a partial list of users who were assessed on the HeadMouse™

Case 1 AGE: 6, DIAGNOSIS: CP, Average to above average cognitive ability
Needs: Text input and educational skill development.
Case 2 AGE: 10, DIAGNOSIS: CP, Average cognitive ability
Needs: Communication and text entry.
Case 3 AGE: 28, DIAGNOSIS: CP, Above average cognitive ability
Needs: Text entry and telecommunication access.
Case 4 AGE: 52, DIAGNOSIS: MS, Average cognitive ability but, with memory problems
Needs: Text entry and CD ROM access.
Case 5 AGE: 11, DIAGNOSIS: SCI, Average cognitive ability
Needs: Text Entry, educational skill development and leisure.
Case 6 AGE: 35, DIAGNOSIS: SCI
Needs: Text entry, Macintosh™ operating system and CD ROM access.

Results

The Usefulness of the HeadMouse™

Case 1 was able to successfully access two to four targets. This is sufficient to develop on screen keyboards that may develop and or enhance literacy skill, but, insufficient to provide her with access necessary for text input.

Case 2 could manage communication access and text entry providing she used a large on screen keyboard.

Case 3 could successfully enter text but, controlling the graphical user interface would be motorically too demanding. Case 3 found it difficult to move her head for cursor movement and still read the screen. She got dizzy because she was not used to moving her head so much. We anticipate these physical problems would diminish with practice.

Case 4 became quite good at calibrating, however, it took him a long time to learn this concept. He could target quite well, but, some days he had spasms which made the HeadMouse™ unusable. The mouse manipulation program and the Macintosh operating system were cognitively too demanding for him.

Case 5 had sufficient head control, adequate ROM, and the necessary cognitive skills to use the computer for text entry and mouse manipulation.

Case 6 was successful with the HeadMouse™. It came quite naturally to her because she had previously used a HeadMaster™. She is using the HeadMouse™ with a sip/puff switch, but, will be trained to use the mouse manipulation softwar

Strategies

The following is a list of strategies that were identified while assessing the abilities of potential HeadMouse™ users. The list is by no means exhaustive. Some of the issues are general, and can be applied to other access techniques. Likewise, general principals and strategies on using other access techniques can be used for the HeadMouse™. An excellent example are the strategies on training users for light pointing (1).

1) Start Simple
- For pointing: Depending on the users cognitive level, use on an onscreen keyboard that has letters only (Ke:nx™ or ScreenDoors™) or draw a few picture targets. First, let the the user try pointing while you click with the ability switch. For mouse manipulations: use Magic Cursor™ with finder or a drawing program. Demonstrate mouse manipulations with the standard mouse first then demonstrate mouse manipulations with the HeadMouse™. Finally, let the user try.
- For text entry use a simple word processor.
- Stay simple if you can. The fewer "fancy" items the better.

2) Take it slow. Add one new idea/function at a time. Let the user master it, then move on.

3) Training
- Have someone, on site preferably, that will provide training. Perhaps, find a volunteer. Practitioners simply do not have enough time to spend on training with the user.
- Determine the best way that user learns and use it. For example, the user may need to have kinetic feedback so it might be best to start out with a mouthstick and MouseKeys™ until they have the basics of the computer understood.

4) HeadMouse™ Setup

- Ensure the reflecting dot is in good shape. It will not work well if it is folded or torn.
- Use mouse control panels to adjust the mouse tracking speed. This can give users more cursor movement with less head movement. This is also useful when the user is positioned far from the HeadMouse™ receiving unit. Some Macintosh™ control panels available are: Kensington Trackball™ Mouse Drivers, Apple Control Panel: Mouse, Shareware Control Panel: Pointing Device, Shareware Control Panel: Mouse II and on IBM compatible computers there is a High End Mouse Driver by Microsoft.
- Do not increase mouse speed too much because it makes it difficult to stay still on a target.
- Adjust the cursor sensitivity in the Magic Cursor™ preferences. Some of the control panels also have adjustments for jitter.

5) Positioning of HeadMouse™
- Put the HeadMouse™ on a mounting arm. This is useful when the user does sit completely upright or is a long way from the monitor. The HeadMouse™ receiving unit should be perpendicular to the plane of motion of the user.
- Ensure the HeadMouse™ is perfectly stationary. If it sways the cursor will jitter even if the user is still.

6) General Computer Software Setup
- Automate as much as possible so the user only has to get the HeadMouse™ dot put on and the computer power on. Put the necessary applications in the start up folder.
- Save preferences for each program used: Word Processor (ie. the size of text, shape of window), onscreen keyboard (size of keyboard, particular layout) and MC (sensitivity, speed, short cuts).
- Use At Ease™, an application launcher, so the user does not have to deal with the Macintosh™ operating system.
- Try not to use "fancy" programs, the more applications running the harder it is on the user and the applications.

7) Computer Hardware
- If possible, leave the computer on.
- If the computer does have to be turned on and off due to overheating or a crash set it up with an ability switch so the user can do it.
- Attach both the HeadMouse™ and the regular mouse to the computer when training. If the computer does not have two ADB ports, find a Y connector, because switching cables is distracting.
- Use a screen saver program for the monitor.

8) Memory Problems
- Draw the three shapes of Magic Cursor™ and paste them next to the computer.
- Draw a flow chart of the commands.

9) Positioning of User
- An occipital head rest or chin rest can give more stability to the head and help prevent fatigue.

Conclusion

Overall, the HeadMouse is just another access method that must be matched to an individuals needs and abilities. It works well for certain individuals, but, is not a universal solution to all computer access issues. Hopefully, some of the limiting factors, like constant recalibration, can be eliminated through future hardware improvements.

Through working with these clients we have identified some strategies to follow next time we assess the effectiveness of using HeadMouse™ as an access method.

References

1. Blackstone, S.W.(ed.). "Light Pointing: Abandoned Too Soon?". Augmentative Communication News, 1(2), pp. 1-3, May 1988.
2. Brady, M.E., Doumas, T.A., and Vanderheiden, G.C. "Two HeadPointing Input Techniques - A Comparative Study". Proceedings of the Second International Conference on Rehabilitation Engineering combined with the RESNA 7th Annual Conference, pp 48-49, 1984.
3. Szeto, A.Y.J., Allen, E.J., and Littrell, M.C. "Comparison of Speed and Accuracy for Selected Electronic Communication Devices and Input Methods". AAC Augmentative and Alternative Communication, Volume 9, pp. 229-241, December 1993.

Trademarks:
HeadMouse™ is a trademark of Origin Instruments, Inc.; Macintosh™ MouseKeys and At Ease are trademarks of Apple Computers, Inc.; HeadMaster™ is a trademark of PRC Inc.; Ke:nx™ is a trademark of DJDE; Kensington Trackball™ is a trademark of Kensington, Inc.;

Kim Adams
Madenta Communications, Inc.
9411A 20 Avenue
Edmonton, Alberta, Canada, T6N 1E5

462

Using AppleEvents to Increase Accessibility on the Macintosh

Randy Marsden, P. Eng.
Jeff Lewis
Madenta Communications Inc. (Edmonton, Canada)

Abstract

To ensure complete access to mainstream software by people with disabilities, there is a need for special adaptive software to not only communicate with the computer's operating system, but also directly with the mainstream software application itself. This paper explores such communication on the Macintosh computer platform using an inter-application communication protocol known as "Apple Events".

Background

Mainstream software developers make certain unfortunate assumptions about the users of their software. Assumptions such as their ability to use a mouse, keyboard, see the screen, and hear the audible feedback. These assumptions result in obvious barriers to people with disabilities in using the mainstream software.

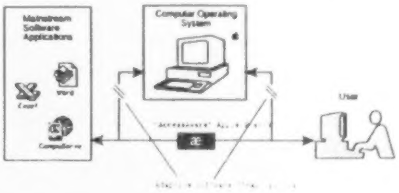
Third party adaptive technology developers have done much to circumvent these barriers. Software such as screen readers for the blind, on-screen keyboards for the physically challenged, and scanning solutions have made most mainstream software "accessible" to many people with disabilities.[1]

Statement of Problem

These solutions are merely "retrofits" to the operating systems on which the mainstream software resides. The mainstream software generally uses "calls" to the computer's operating system to provide most of its user interface. These calls can be "trapped" by the adaptive software - a sort of hi-tech spying on the communication that goes on between the mainstream software and the operating system (see figure 1).

Through these traps, the adaptive software can learn much about what it going on in the computer. It can also "fool" the operating system into thinking a keyboard was typed on, a mouse was moved, and so on, to mimic the actions of a keyboard and mouse user.

The problem with this approach is mainstream software doesn't *always* go through the computer's operating system to do its business. Many times it takes care of the user interface directly on its own. This makes it impossible for the adaptive software to "spy" and provide alternative access for people with disabilities. For these instances, it is necessary for the adaptive software to communicate directly with the mainstream software application. Trapping the operating system alone isn't enough - the mainstream software and adaptive software must also talk to each other directly.



This paper outlines one implementation of such a solution, using the inter-application communication protocol know as "Apple Events" on the Macintosh computer.

Approach

In 1991, Apple introduced AppleEvents to the Macintosh operating system (now called MacOS). AppleEvents were intended to provide a major extension to the existing event based messaging system already in use in MacOS, specifically to encourage developers to treat their documents as collections of objects (paragraphs, words, circles and the like) and to allow unrelated programs to query each other about the nature and number of such objects as well as to request actions to be done to these objects.

The AccessAware Suite of AppleEvents are still being defined, but at this time, we are proposing the following as a starting point:

Message	Reply	Comments
Are you AccessAware?	Yes/No	No reply is same as no
Describe item <n>	Item Desc	
List items owned by <n>	List	
Do <action> on item <n>	Yes/No	Depends on item type
Move pointer to item <n>	Yes/No	
What item is under <point>?	Number	
Which item is next after <n>?	Number	

---

[1] Accessible Design of Consumer Products 1991 (1-4)

BEST COPY AVAILABLE

AcessAware Standard

The screen and its parts are defined to be collections of items which are described as follows:

Field	Content	Bytes	Meaning
Byte order	code	2	'MM' or 'II' only.
Message size	integer	2	
Item number	long	4	
Item parent	long	4	parent group
Item count	long	4	sub items (group)
Item type	code	2	Part code
Item action	bits	1	Action code
Item state	bits	1	State code
Item top	integer	2	
Item left	integer	2	
Item width	integer	2	
Item height	integer	2	
Item name	text	32	short name
Item descriptio	text	256	What the user can be told

There are currently a relatively small number of item types, but we have found that so far, they can describe completely just about every application screen fairly easily. Current, the defined item types are:

Type	Name	Description
CO	Control	Icon, button... action regions
GR	Group	Collections of items
N	Indicator	Gauges, lights... information
MN	Menu	Collections which are menus
TX	Text	Controls which have text
WN	Window	Collections which are windows/palettes

The protocol and its parameters are not meant to be a 'final' design, but rather a starting point. We think we've put together a protocol which can handle just about any system, but of course, we don't know every system and the myriad variations out there. We hope that this protocol will be flexible enough to handle any surprises we come across.

Since the complete protocol is outside the scope of this paper, copies of the complete protocol including programming examples, will be made available at the session and afterwards by request.

At the highest level, the entire visible area of the screen constitutes one group item which contains within it all the information about the system or application by way of a collection of subordinate items.

A complex control like a scroll bar is represented as a group containing subordinate items. Windows and menus, in fact virtually all complex interface objects including floating palettes, can be broken down into collections of simpler objects and collections of objects.

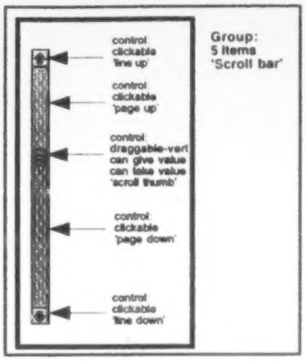


Fig. 2 - A scroll bar broken down

Intermediary program such as keyboards, screen describing systems and pointing assist software and hardware can interrogate each item, obtain position, status and information about what kinds of actions can be done to this item as well as obtaining a meaningful text description and name for that item.

An assistive program for visually impaired users could ask the application to tell it what is under the pointer and more, what should the user be told this item is called and what it does. This would be a massive improvement over the current guessing game based on general attributes and related text where a tremendous number of assumptions are made about the application.

Implications

The down side of this idea means that everyone who wanted to play in this field would have to implement not merely a whole new system within their program, but have to design suites of event messages which also had to be shared with everyone else. The obvious fear here is that your application might end up being little more than a server for some competitor's program. As well, since this meant that every AppleEvent server has to be launched whenever there is any call for its use, AppleEvent based applications tended to require more memory and tended to be slower.

These, plus the very long delay in delivering the scripting language (AppleScript) and a Finder which could be scripted (which accounts for the majority of scripting needs), meant that few applications took any advantage of AppleEvents or implemented any but the most trivial and required of events.

Fortunately, things have improved and the situation looks much brighter. First, the standard amount of memory delivered on all Macs shipping provides more than adequate amounts of memory for AppleEvents.

Second, as of System 7.5, the Finder is completely scriptable and people are actually starting to use AppleScript and are learning how to write the Mac equivalent of batch files - and are running into the wall of applications which do not support AppleEvents. Thus, the tide seems to slowly be turning as more users are demanding that the applications they use be scriptable and thus support AppleEvents.

On first examining the AppleEvents architecture, it would seem that implementing AppleEvent support is difficult, but fortunately that's more a case of poorly written documentation that an actual problem with AppleEvents. In reality, adding AppleEvent support to an existing Mac application consists of adding one new event type to your existing event loop (kHighLevelEvent) which simply calls one subroutine (AEProcessAppleEvent). The sorting out of events and where they go is handled by the operating system.

As well, for each event you plan to implement, one subroutine (handler) should be written which actually handles what should happen when that event is received and somewhere in your initialization, the handler has to be registered (AEInstallEventHandler). Each handler has to unpack any additional information and create a reply, but that is fairly simple.[2]

The largest expense lies in deciding how much access you want to give to the user and the intermediary applications and how much effort you want to make in laying out all of the components of the interface and building descriptions of them for access by that application.

Clearly, in some cases this is not excessively difficult. Menus tend to be static, windows rarely grow extra parts - but something as complex as a drawing application would want to give the user information about every object drawn on the page. Apple also expects this information in its own suite of AppleEvents and application such as Canvas 3.0 in fact, already provide this information.

For them, adding the relatively simple AccessAware suite would be easy.

Discussion

In the environment brought about today by the American's with Disabilities Act, many mainstream software developers are groping with the concept of "Universal Design" and "Accessible Formats". To these developers with little or no knowledge of Assistive Technology issues, it seems a formidable task to write their software in such a way that people with disabilities can use it. Most simply choose to ignore the issue.

Standards such as the one presented in this paper ("AccessAware") can provide these developers with the much needed simple approach to making their software accessible. By simply supporting the AccessAware Apple Event suite, these companies can ensure their software meets the requirements of the ADA, with the addition of the special third party Adaptive software.

Conclusion

To draw an analogy, if the mainstream software application is a building, the AccessAware standard is the specification for a wheelchair ramp into that building. Once the building's owner provides that ramp (a relatively simple task), all sorts of wheelchairs (ie. adaptive software) can gain easy access to all the exciting things inside the building. Without the ramp, all people with disabilities will be able to do, is look in from the outside and wonder what its like. Standards such as the AccessAware Apple Event Suite can pave the way to true equal access to all software by people with disabilities.

References

(1) Accessible Design of Consumer Product, Working Draft 1.7, Gregg and Katherine Vanderheiden 1992

(2) Inside Macintosh:Events, Addison Wesley, 1994

(3) AccessAware Protocol Specification. First Revision. The AccessAware Group (Madenta Communications, Berkeley Systems, Intellitools Inc, Apple Inc.) 1993

(4) AccessAware Protocol Specification. Second Revision. Madenta Communications, et al, 1995.

---

[2] Inside Macintosh:Events

THE POTENTIAL OF MULTIMODAL INTERFACES FOR THE BLIND : AN EXPLORATORY STUDY

Yacine BELLIK & Dominique BURGER***
*LIMSI-CNRS, **INSERM, France

ABSTRACT

Multimodal interfaces are the subject of considerable research world-wide. This paper describes a joint project funded by two French research organisations, with the cooperation of an institute for the blind. This project applies multimodal interfaces to provide improved computer access for the blind. A multimodal text editor is described. It has been designed to provide enriched texts, direct manipulation and immediate feedback to text editing tasks, such as reading and modifying text attributes, selecting, copying, moving, or deleting parts of text, navigating within the text and getting additional information on words (definitions, annotations...).

KEYWORDS

Non Visual Interfaces, Multimodal Interfaces.

INTRODUCTION

The developments that have taken place in Human-Computer Interaction (HCI) over the past years have had contradictory effects on blind people (3). The advent of refreshable electronic Braille displays, and text-to-speech synthesisers in the late seventies opened up new opportunities for the social and professional integration of the blind. Many kind of jobs and activities became accessible thanks to workstations that were adapted to their special requirements. Despite certain difficulties in making the adapted interface as friendly as were screen-based interfaces, this was a time of great hope. The graphical user interface (GUI) revolution that has recently overtaken micro-computers has become a source of worry for the blind (4). One reason is that the bitmap display technology on which these interfaces are based means that access products based on the principle of reading characters from screen memory can no longer be used. But more fundamentally, blind people were led to believe that new generation software would result in the screen being covered with images, making its meaning impossible to decipher. "Because developers used a heavily visual design metaphor, it was assumed that blind people would never be able to access GUI systems" (1). The gradual evolution of software architecture, coupled with successes in research and development on HCI, now seems to be about to create new conditions for the design of non-visual human-computer interfaces that will provide a better match for needs of blind users (2). This study resulted in the establishment of a research and development program with the objective to explore the potential of multimodal solutions for constructing non-visual interfaces. This paper describes the initial results of the research program : a prototype application for text editing (Meditor). It is important to notice that this work does not deal with the problem of GUI accessibility by the blind. However, it aims at showing that multimodality constitutes an important factor which must be integrated in the solution of this problem, to have friendly non-visual interfaces.

MULTIMODAL INTERFACES

Human beings perceive the external world using the five senses of touch, hearing, sight, smell and taste. They interact with it by producing sounds, gestures, etc. These are referred to as *communication modes,* and they define the nature of the information used to communicate (visual mode, sound mode, gestural mode, etc.). A *modality* defines a particular form of a communication mode. Thus, noise, music, and speech are modalities of the sound mode. In most situations, natural communication between human beings is *multimodal,* as it combines several modes and modalities. Computer scientist are interested in producing *multimodal interfaces* that can integrate multimodal features and so make computer behaviour closer to human communication paradigms, and therefore easier to learn and use. This has been possible with the advent of new devices (speech recognizers and synthesizers, datagloves, touchscreens...). Multimodal interfaces are the ultimate HCI systems that can manage various and complex I/O information (5).

MEDITOR: A MULTIMODAL TEXT EDITOR

Meditor has been developed bearing in mind the many problems that blind people encounter when they have to access or manipulate textual material. Not only is text material deprived of some of its original features when it is presented in Braille on paper or by a refreshable Braille display, but manipulations as simple as underlining or annotating texts are a great challenge. This is particularly dramatic in education, where paper-based documents are fundamental for many exercises in which children construct, verify and reinforce forms of thinking by carrying out specific manipulations. We have consequently designed Meditor to overcome these difficulties, and to be an interactive support for the development of teaching and training material for blind students. The design work was carried out in close cooperation with two blind users, a teacher and a Braille proof-reader.

Hardware configuration

The computer environment in which Meditor was implemented is the basic workstation used by blind students at their institute. It includes a desktop PC, a Braille terminal and a French text-to-speech synthesiser. A speech recognition system has been added (fig. 1).

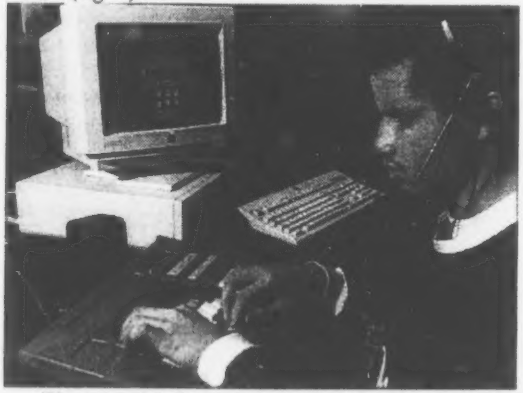


Figure 1. *Meditor : A multimodal text editor.*

Each cell of the Braille terminal presents a character on an 8-dot Braille matrix. The Braille terminal used, allows users to point at any character within the line by pushing a button located in front of the corresponding cell. The speech recognition system is speaker-dependent and allows recognition of continuous speech. A vocabulary of about 60 words is used.

Functionality

Meditor was designed to provide blind users with the main functions of a simple full-page editor. The user can perform the following tasks :

- read a text with embedded character attributes such as style, colour, font, or size
- select, copy, move, or delete parts of a text with immediate feed-back
- modify text and/or attributes
- search strings or text with specific attributes
- read parts of text, using speech synthesis
- insert, consult and modify additional information on words (annotations).
- etc.

Design rules

Concerning inputs, the general principle consists in selecting an entity and then apply a command to it. By adding speech, several types of selections can be made through the same pointing operation. The user has just to say the name of the entity while clicking on any character of this entity. For instance, to select a sentence he has to say "*sentence*" while clicking on any character of the desired sentence. To select a paragraph he has to say "*paragraph*" instead of "*sentence*". If a command is executed without any explicit selection, it is applied to the word in which the pointing character belongs. The standard keyboard or the Braille keyboard are used to enter text, file names, searched strings etc.

Concerning outputs, the Braille display is used for text presentation, while auditory messages (speech and beeps) are used to deliver feed-back information about user commands, and information about the displayed text (current line number, number of pages, etc.). Attributes are presented through 3 levels. When a line containing particular attributes is displayed, a beep is produced. This is the first level. It indicates that particular attributes are present within the current line. The eight-dot matrix of the two first characters of the concerned entity are then set up[1]. This is the second level. It informs the user more precisely about the location of the particular attributes. If the user wants more information about the type of attributes (colour, style, etc.) and the type of the concerned entity (word, sentence, paragraph...) he has just to click. A speech message containing the whole information is then synthesised (fig. 2). This is the third level.

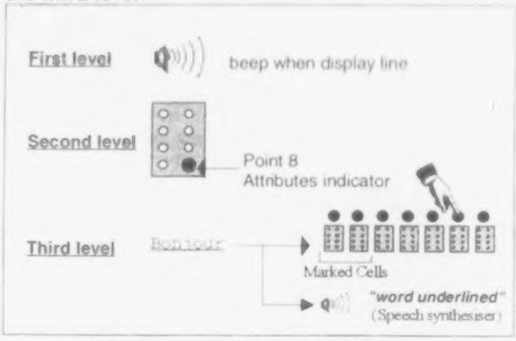


Figure 2. *Attributes presentation.*

Interaction examples

To put a word in italic

The user says "*italic*" while clicking on any character of the word on the Braille terminal.

---

[1] Giving that blind are used to read 6 dots Braille, only the two first characters are marked to ensure that the information will be detected without disturbing the reading process.

BEST COPY AVAILABLE

To place a character into an exponent position
The user says "*character exponent*" while clicking on the corresponding character.

To delete a part of the text
1) The user says "*begin selection*" while clicking on the first character of the string to be deleted, 2) then says "*end selection*" while clicking on the last character, and 3) says "*delete*" to complete the command. The message feed-back "*selection deleted*" is then generated by the speech-synthesiser.

First stage evaluation
The application is currently being thoroughly evaluated and the results will be soon available. We describe here the preliminary evaluation that has been done with two blind subjects.

Evaluation conditions
The first stage evaluation of Meditor was based on three simple but realistic tasks carried out by the two blind subjects during two trial sessions of two hours each. The following three tasks were performed :

Task 1 : An exercise in grammar. The subjects had to colour code words of sentences according to their grammatical class. Verbs were made red, while nouns were made green.

Task 2 : To read a text on prehistory. The definitions of some specific words were available on request, via the speech synthesiser. A special attribute was used to mark these words. The command to access the definition of a word is : say "*definition*" while pointing at the word.

Task 3 : Text-editing. The subjects were asked to correct spelling errors in a text and to reorganise it using "*Cut*", "*Copy*" and "*Past*" commands.

Results
Both subjects agreed that the interface was intuitive. The combination of auditory and tactile information to translate the attribute information did not disturb their reading of the text. They found no difficulty with the use of visual terms for colours that were considered as particular attributes. The combination of pointing gestures and spoken commands appeared to be quite natural. Only a few minutes explanation was necessary for them to understand and memorise the commands, the vocabulary and the principles of interaction. Nevertheless, they were given a four-page Braille direction for use to help them remember the vocal commands. It was almost never used, indicating that the memory load was minimal. Undoubtedly, more efforts would have been required to memorise keyboard functions and combining keys on the keyboard, as when people can not use a mouse. The control by speech allowed the subjects to concentrate on tactile information and to perceive immediate feed-back of commands. It also alleviated the workload as physical actions are minimised. The interaction principles seem quite close to direct manipulation in a GUI, as users can directly act on the objects through pointing operations. The principle of combining speech and pointing gestures, considerably increases the power of expressions and the interaction rapidity. For instance, a command such as "*Sentence bold italic*" while pointing at a character of the sentence, represents a contraction of several commands in a classical text editor.

CONCLUSION

This paper has described a study exploring some aspects of a multimodal solution to the problem of computer accessibility by the blind, through a concrete application. This study has indicated that multimodal interfaces represent a promising solution to improve computer access by the blind. An interesting perspective now is to study how multimodality can be integrated in the problem of GUI accessibility. The study has also revealed the need for a multidisciplinary approach in which blind users, specialists in fields, such as cognition, education, ergonomics, computer science and neuroscience, cooperate to create the models and guidelines necessary to design non-visual interfaces.

ACKNOWLEDGEMENTS

We wish to thank Y. Felix, J.F. Colas, C. Coudert and A. Junior from the INJA institute.

REFERENCES

(1) J. Berliss, "Software Solutions to the Problem of GUI Inaccessibility to Blind Persons" in *Non-Visual Human-Computer Interactions*, D. Burger and J. C. Sperandio, eds., Montrouge, France: John-Libbey Eurotext, 1993, pp.131-143.

(2) C. Stephanidis, A. Savidis, G. Chomatas, N. Spyridou, M. Sfyrakis, and G. Weber, *Access to Graphical User Interfaces by Blind People*, Concerted Action on Technology and Blindness, European Community, 1991.

(3) L. H. Boyd, W. L. Boyd, G. C. Vanderheiden, "The Graphical User Interface : Crisis, Danger and Opportunity", *Journal of Visual Impairment and Blindness*, vol. 84, 1990, pp. 496-502.

(4) D. Burger, "Could Computer Tools for the Visually Handicapped be Someday as Friendly as those for Sighted People? ." *IEEE Transactions on Rehabilitation Engineering*, Jun. 94.

(5) J. Coutaz, "Multimedia and Multimodal User Interfaces : A Taxonomy for Software Engineering Research Issues", *East/West Human Computer Interaction'92*, St Petersburg, August, 1992.

Yacine BELLIK,
LIMSI-CNRS, BP 133, 91403 Orsay Cedex France,
Tel : (33-1) 69-85-81-10, Fax : (33-1) 69-85-80-88,
E-mail : bellik@limsi.fr

METAWIDGETS FOR MULTIMODAL APPLICATIONS

G. Bowden Wise and Ephraim P. Glinert
Dept. of Computer Science
Rensselaer Polytechnic Institute
Troy, New York 12180
Email: wiseb@cs.rpi.edu, glinert@cs.rpi.edu

ABSTRACT

We present a new approach to multimodal systems development that enables end-user applications to present information in alternative modalities, thereby making them useful even in situations where the default output modality is unacceptable to the user. We discuss the implementation of a software framework for constructing multimodal applications using the multimedia PCs that are available today, and outline our plans for the future continuation of this work.

INTRODUCTION

Advances in computer-human interface technology often lead to new interaction techniques which enable computers to better communicate with their human counterparts. Since their inception, computers have communicated primarily through visual displays. The recent explosion in multimedia systems, which adds sophisticated audio capabilities to the computer's output channels, allows today's users to not only see the information presented to them but to hear it as well.

One of the challenges for developers of multimedia applications is to determine which sensory modality is best for the information that is being presented. Existing multimedia applications typically present a variety of different kinds of information, each in a prescribed (predetermined) modality. One drawback to this strategy is that the inflexible assignment of information to a particular modality by the designer can lead to situations in which the chosen output format will not be acceptable to a given user. Environmental conditions, such as a noisy factory floor, can preclude the use of sound. Users often run several applications simultaneously, absorbing information from all of them; too much information in a single modality can lead to sensory overload, resulting in the loss of information. Perhaps most importantly, many users have sensory impairments and cannot interpret information presented in some modalities.

In our view, application designers can no longer allocate information to a particular modality. Rather, applications must become *multimodal* so that they are able to take abstract, high level information and display it using the available sensory modalities as (changes in) the working environment, individual user needs and preferences, and other factors (both extra- and intra-system) dictate.

In what follows, we present a new approach to multimodal systems development that defines the concepts and constructs for developing end–user applications as well as the tools and system information needed for the underlying core system software. We also discuss the development of a software framework for implementing multimodal applications that run under Microsoft Windows using the power of multimedia PCs available today.

MULTIMODAL SYSTEMS DEVELOPMENT

A multimodal interface requires a very different environment than that now required by graphical user interfaces (GUIs). Clearly, presenting information dynamically in more than one modality will require careful management, if all the information is to be understood rather than lost. Below, we present concepts and an associated development methodology for end–user applications that are empowered to present information in alternative modalities.

Metawidgets

Typically, applications which run under today's GUIs are developed using libraries of *widgets* which represent familiar user interface elements such as windows, scrollbars, icons, buttons, and dialog boxes. However, because the graphical nature of these widgets has already constrained them to the visual modality they are too low-level to be of use directly by a multimodal application.

Multimodal applications require a higher level of abstraction in order to interact with the user in several modalities. For this reason, Glinert and Blattner (2) have proposed the use of *metawidgets* as multimodal widgets. Metawidgets represent some informational abstraction of the application which is to be presented to the user.

Each metawidget contains a repertoire of representations, each of which may be in a different sensory modality, as well as methods for selecting among them. The selection mechanism can take into account both the user's preferences and extra– and intra–system factors to determine which representation is optimal for

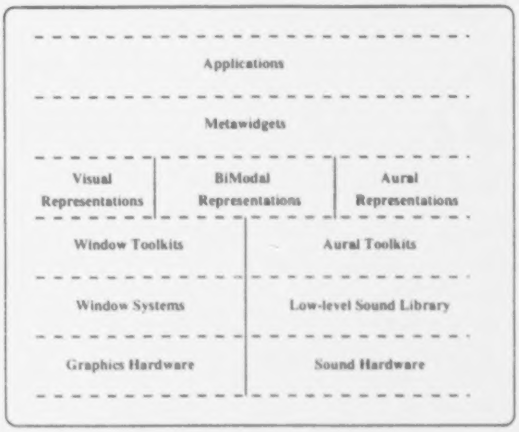


Figure 1: A layered approach to multimodal systems development.

presentation at that time. Metawidgets also possess the ability to *metamorphose* (1) or change their representation from one modality to another as conditions dictate.

Representations

The representation of a metawidget, which could be visual or aural, is what actually gets presented to the user. Representations, like GUI widgets, are confined to a particular modality. Toolkits of widgets are, therefore, appropriate for constructing representations. Visual representations can be constructed using the user interface toolkit for an application's target GUI platform. Similarly, auditory representations can be constructed using aural toolkits. Bi-modal representations can be created by combining widgets from visual and aural toolkits into one representation.

A Layered Approach

Metawidgets, with their associated representations, provide natural building-blocks for developing multimodal applications. We propose a layered approach as shown in Figure 1. Using this approach, developers construct applications using metawidgets. A suite of representations for each metawidget may also have to be developed if such representations do not already exist in the toolkits.

Cognitive Load

As previously mentioned, too much information in any one modality may lead to sensory overload, making it impossible to interpret any more information in that channel. But even when simultaneously exploiting two (or more) modalities, information can be lost. We propose defining a set of cognitive resources for each modality that can be used by the underlying core software to measure the contribution to the user's total load by each metawidget.

Core Multimodal System Software

An effective multimodal environment must, therefore, maintain data on the currently active metawidgets and their associated representations in order to determine the total cognitive load imposed on the user. When overloading is detected, the system software can request that one or more metawidgets metamorphose their representation to another modality in an attempt to reduce the cognitive load.

The core multimodal software contains the following tools to manage the overall presentation of information to the user in a multi-application environment:

- **Resource monitor.** This tool is responsible for determining the contribution to the total cognitive load by each application running in the environment.
- **Presentation manager.** This tool manages the presentation of information so that the user does not become overloaded. The cognitive load, user preferences, and other system information will determine whether information presented to the user needs to be transformed into a representation in another modality.

Both of these tools run in the background and co–exist with user applications, as illustrated in Figure 2.

CURRENT STATUS AND FUTURE WORK

Applications developed to run under a multimodal architecture such as ours have a similar architectural structure and must also utilize common code to work with the underlying core software. An implementation of the architecture will most likely contain a substantial amount of reusable code. Object-oriented languages such as C++ (our chosen implementation language) facilitate software reuse through a reliance on class libraries. Class libraries of metawidgets and representations can be used to implement applications.

However, it is the collaboration and interconnection between the classes and core software tools that is important in the multimodal interface. For this reason, a software *framework* (3) is an ideal development environment for the implementation of multimodal applications on a particular hardware and operating system platform.

We have begun the implementation of a software framework that will support construction of multimodal applications to run on a multimedia PC under

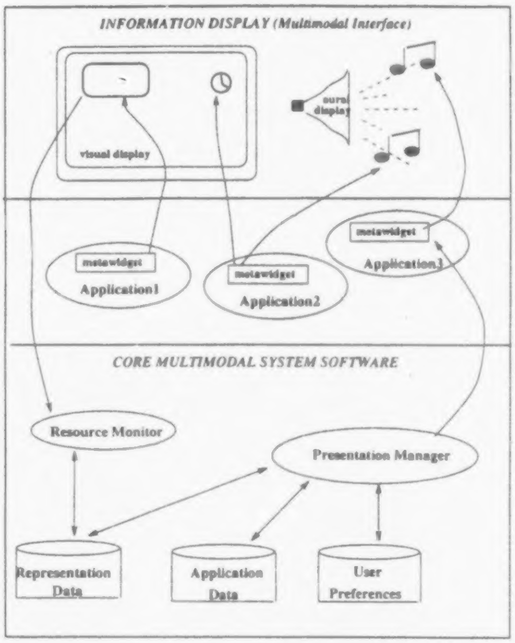


Figure 2: Run-time view of a multimodal environment.

Microsoft Windows. Figure 3 shows the layered implementation architecture for this platform.

Our implementation will consist of the core multimodal system tools as well as class libraries of metawidgets and representations from which multimodal applications can be constructed. We plan to provide a more detailed discussion of the framework, as well as sample applications, in a future paper.

CONCLUSION

Research in virtual reality suggests that we may soon be able to communicate with computers using our sense of touch, by wearing special gloves and body suits. When these developments become practical, they will add yet another sensory dimension to the human-computer experience. Multimodal environments, such as the one presented here, make it possible for computers to communicate using whatever sensory modalities are available.

With the emergence of personal digital assistants (PDAs) and ubiquitous computer devices that blend into our surroundings it is clearly impossible for a single human sense to be useful for all situations. Multimodal interfaces provide a new form of interaction that will enable these new computers to fit into our lifestyles. We hope that our multimodal framework not only will make it possible for users with a variety of disabilities to use computers as first-class citizens, but will also provide a new methodology for building applications in general.

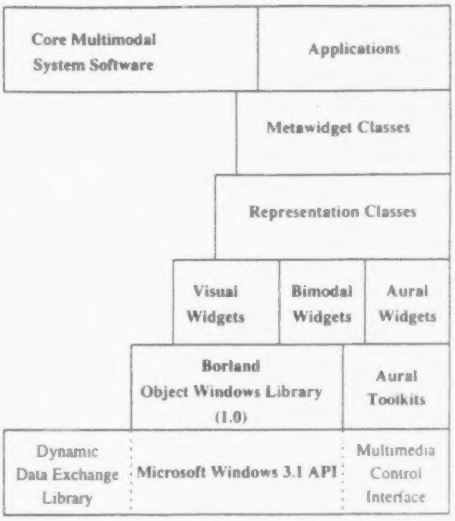

Core Multimodal System Software
Applications
Metawidget Classes
Representation Classes
Visual Widgets
Bimodal Widgets
Aural Widgets
Borland Object Windows Library (1.0)
Aural Toolkits
Dynamic Data Exchange Library
Microsoft Windows 3.1 API
Multimedia Control Interface

Figure 3: Current system implementation platform.

REFERENCES

[1] BLATTNER, M. M. In our image: Interface design in the 1990s. *IEEE MultiMedia 1*, 1 (Spring 1994), 25–36.

[2] BLATTNER, M. M., GLINERT, E. P., JORGE, J. A., AND ORMSBY, G. R. Metawidgets: Towards a theory of multimodal interface design. In *Proc. COMPSAC'92, Chicago* (September 22-25 1992), IEEE Computer Society Press, pp. 115–120.

[3] WIRFS-BROCK, R. J., AND JOHNSON, R. E. Surveying current research in object-oriented design. *Communications of the ACM 33*, 9 (September 1990), 104–124.

ACKNOWLEDGEMENTS

This research was supported, in part, by the National Science Foundation under contracts CDA-9015249, CDA-9214887, CDA-9214892 and IRI-9213823. Special thanks to Rick Kline for his helpful comments on an early draft of this article.

BEST COPY AVAILABLE

INTEGRATING THE VISUAL AND NON-VISUAL WORLDS: DEVELOPING DUAL USER INTERFACES

Anthony Savidis and Constantine Stephanidis
Institute of Computer Science, Foundation for Research and Technology-Hellas (FORTH),
Science and Technology Park of Crete, Heraklion, Crete, GREECE

ABSTRACT

Accessibility of Graphical User Interfaces by blind people is handled today by run-time adaptations of specific graphical environments. Such approaches are restrictive since the resulting non-visual dialogue is merely a reproduction (adaptation) of visual dialogues originally designed to meet the specific needs of sighted people. The concept of Dual User Interfaces has been defined as a more appropriate basis for integrating blind and sighted users. An interface development system, called HOMER, enabling the high-level construction of Dual User Interfaces has been designed and developed and is currently tested for constructing interactive applications with Dual User Interfaces.

BACKGROUND AND STATEMENT OF THE PROBLEM

Currently, accessibility to Graphical User Interfaces by blind users is enabled through systems which reproduce the lexical structure of User Interfaces (i.e. interaction objects and their relationships) to a non-visual form (1). Even though such approaches partially solve the problem of accessibility, there are still a number of issues to be addressed: (i) The dialogue is reproduced based on lexical level information and no knowledge on the application semantics or the application domain can be extracted. (ii) Reproduction of the dialogue to a non-visual form is based on the visual dialogue structure which has been constructed in accordance to the specific needs of sighted users. Moreover, the role of the designer for the non-visual User Interface is totally neglected; fixed dialogue decisions are taken for all non-visual User Interfaces. (iii) Considering that the trend of User Interface software technology is directed towards highly visual interaction methods such as virtual reality and 3D representations (i.e. visual reality), it is expected that the employment of adaptation oriented techniques will become unrealistic or meaningless in the future. (iv) Currently, there are no methods or tools available to enable the development of non-visual User Interfaces. If the implementation of a dedicated non-visual application is required, interface developers are faced with the problem of *lack of tools*.

DESIGN REQUIREMENTS

In order to address all these issues and to practically facilitate integration of blind and sighted users, the concept of Dual User Interfaces has been defined. A Dual User Interface is characterized by the following properties: (i) it is concurrently accessible by blind and sighted users, (ii) the visual and non-visual metaphors of interaction meet the specific needs of sighted and blind users respectively, (iii) the visual and non-visual dialogue designs meet the specific needs of sighted and blind users respectively, (iv) at any point in time, the same internal (semantic) functionality should be made accessible to both user groups through the visual and non-visual "faces" of the Dual User Interface, and (v) at any point in time, the same semantic information should be made accessible through the visual and non-visual "faces" of the Dual User Interface.

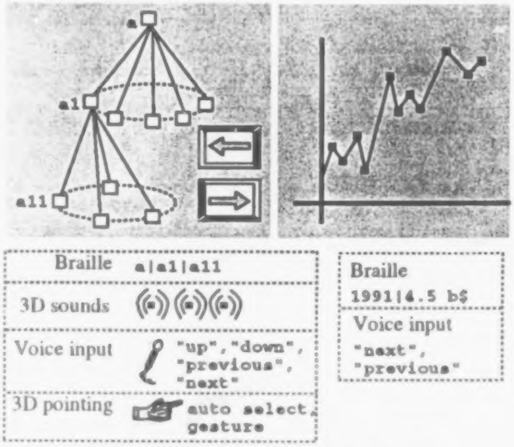


Figure 1: Illustration of a Dual interface.

The first requirement is important for enabling cooperation between a blind and a sighted user in their working environment. The second requirement explicitly poses the need of a metaphor specifically designed for blind users in the non-visual environment; adaptation oriented approaches use the visual Desktop metaphor for non-visual interaction. The third requirement expresses the need for separate non-visual interface design, which is not supported by adaptation oriented methods. Finally, the fourth and fifth requirements specify that the underlying functionality and information structures should be made equivalently accessible, though via different interactive channels. In Figure 1, a simple Dual interface is illustrated depicting hierarchical structures (left part) and numerical values (right part). The visual appearance employs 3D graphics and highly visual symbolisms, while the non-visual dialogue may be structured in a radically different manner and may combine Braille, speech and 3D sounds for output, while 3D pointing and speech is used for input.

Adaptation oriented techniques cannot reproduce such a highly visual dialogue in a non-visual form.

SYSTEM OVERVIEW

The HOMER system (2) has been developed which falls in the domain of User Interface Management Systems. It provides a high-level language, called the HOMER language, for the specification of Dual User Interfaces and it automatically generates the Dual interface implementation from such formal specifications. As it is shown in Figure 2, the HOMER system provides methods to integrate different non-visual and visual interaction technologies (i.e. software libraries for developing interfaces with specific "look and feel").

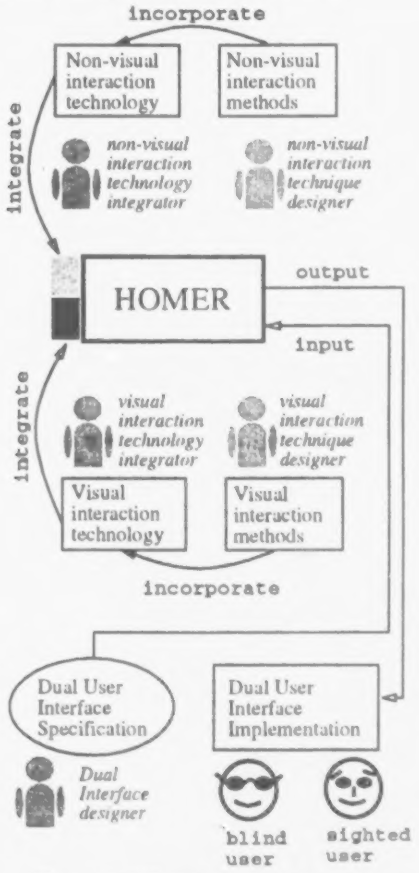

incorporate
Non-visual interaction technology
Non-visual interaction methods
integrate
non-visual interaction technology integrator
non-visual interaction technique designer
HOMER
output
input
integrate
visual interaction technology integrator
visual interaction technique designer
Visual interaction technology
Visual interaction methods
incorporate
Dual User Interface Specification
Dual User Interface Implementation
Dual Interface designer
blind user
sighted user

Figure 2: Different user roles in the context of the HOMER system.

Until now, there was no toolkit available for implementing non-visual User Interfaces, as it is the case with their visual counterparts. For instance, for the MS-WINDOWS™ graphical environment a plethora of development libraries for programming MS-WINDOWS™ based interfaces are provided. The lack of such a basic "instrument" to support non-visual interface development has driven us to the development of such a non-visual interface development toolkit, called COMONKIT, which provides programming libraries for implementing non-visual interfaces supporting speech, non-speech audio and Braille output, while keyboard is used for input. This toolkit has been integrated in the HOMER system. Several interactive applications with Dual User Interfaces have been developed and tested using the HOMER system.

The HOMER system reduces significantly the time required to develop a Dual User Interface since implementation is practically reduced to specification (see Figure 2). This feature enabled us to efficiently carry out testing cycles during early experimentations with Dual User Interfaces. The HOMER language enables different designs for the visual and non-visual faces of Dual User Interfaces to be independently realized and be eventually integrated at the specification level; hence, the visual dialogue is designed for sighted users, while the non-visual dialogue is designed in order to meet the specific requirements of blind users.

The HOMER system has been developed under the UNIX™ operating system, while the Athena widget set of the X WINDOWING SYSTEM has been integrated as a particular visual interaction technology. It has been designed in a way that allows porting to other (multitasking) operating systems to be easily carried out. Special purpose software libraries are provided as part of the HOMER system in order to facilitate the integration of various visual and non-visual interaction technologies.

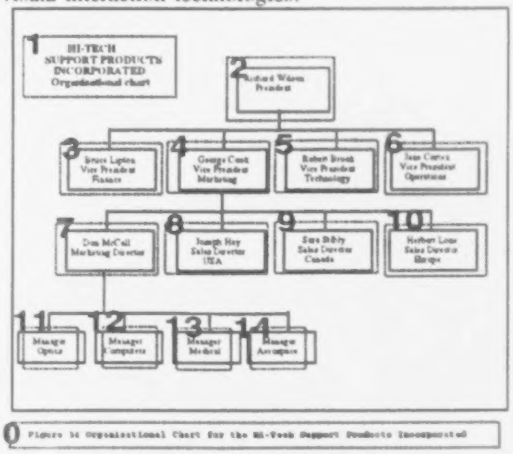


Figure 3: An organizational chart picture having marked the regions which have annotated text.

BEST COPY AVAILABLE

DUAL INTERFACE DEVELOPMENT

A number of different applications with Dual User Interfaces have been experimentally developed by utilising the HOMER system. One such application concerns access to graphics. Currently, access to graphics information is not possible for blind people. Adaptation oriented methods, which are based on filtering of the particular visual graphical environment, are not able to automatically extract the semantic content of pictures since current image understanding methods cannot serve these needs. An experimental interactive application has been built using the HOMER system which enables efficient picture exploration by blind users. Pictures are split into regions which are associated with textual descriptions. Reviewing of picture regions by a blind user is organized by means of a presentation scenario which is structured by the dialogue designer. This scenario identifies alternatives ways for enabling the blind user to "visit" and "explore" the various picture regions. Regarding the visual User Interface of the graphics application, the picture is displayed in the visual screen, while a "highlighter" always displays the particular current region reviewed by the blind user. Also, the associated textual description and the particular reachable picture regions are displayed in text boxes and list boxes respectively. In Figure 3, an organizational chart picture is shown. The various regions are indicated with dashed rectangles and are numbered. In Figure 4, the exploration scenario is provided. From a specific region, the blind user is able to reach all regions reachable in the graph through an arc. Also, interactive facilities to move backward to the recently visited region are provided.

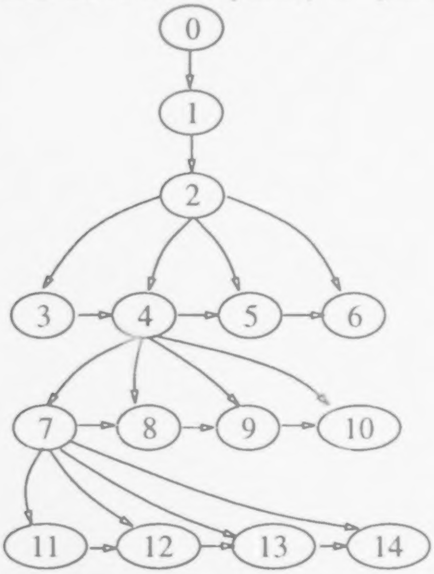


Figure 4: A scenario for exploration of the organizational chart picture.

DISCUSSION

Until now, accessibility of blind users to Graphical User Interfaces has been supported mainly through ad hoc solutions employing adaptations of the visual environment for reproduction in a non-visual form. The concept of Dual User Interfaces is proposed for effectively and efficiently integrating blind and sighted users in their working environments. Adaptation oriented methods cannot support Dual User Interfaces (for instance, there are no facilities for supporting different metaphors or different dialogue designs for the visual and non-visual interaction respectively). The HOMER system has been developed to enable the construction of Dual User Interfaces. It also provides a platform for further experimentation with non-visual interaction techniques and metaphors. This system explicitly supports the important role of non-visual dialogue designer to specify interaction appropriate for blind users. The Dual User Interfaces developed through the HOMER system may run in two modes: *local* mode, in which case the visual and non-visual faces run on the same host, and *remote* mode, in which case the two faces run on different hosts (enabling remote collaboration between a blind and a sighted user).

ACKNOWLEDGMENTS

This work has been partially funded by the TIDE Programme of the Commission of European Union (DG XIII), under the project GUIB-II (TP 215). The partners of the GUIB consortium are: IROE-CNR, Italy; Institute of Computer Science-FORTH, Greece; Vrije Universiteit Brussel, Belgium; Department of Computer Science-FUB, Germany; Institute of Telecommunications-TUB, Germany; IFI, University of Stuttgart, Germany; VTT, Finland; RNIB, England; F. H. Papenmeier GmbH&Co, KG, Germany;

REFERENCES

1. Mynatt, E.D., and Weber, G. *Nonvisual Presentation of Graphical User Interfaces: Contrasting Two Approaches*. In *Proceeding of the CHI'94 Conference on Human Factors in Computing Systems* (Boston, Massachusetts, April 24-28, 1994). ACM, New York, 1994, 166-172.

2. Savidis, A., and Stephanidis, C. *Developing Dual User Interfaces for Integrating Blind and Sighted Users: the HOMER UIMS*. To appear in proceedings of the *CHI'95* conference on *Human Factors in Computing Systems*, Denver, Colorado, May 7-11, 1995.

Dr. Constantine Stephanidis
Institute of Computer Science, FORTH,
Science and Technology Park of Crete,
P.O. Box 1385, GR 71110,
Heraklion, Crete, GREECE
Tel: +30-81-391741
Fax: +30-81-391740
E-mail: cs@ics.forth.gr

PERFORMANCE DIFFERENCES USING OUTSPOKEN ON THE MACINTOSH COMPUTER: SOFTWARE FOR PEOPLE WITH BLINDNESS

Adam E. Krass
Maddak, Inc.
Pequannock, NJ U.S.A.

ABSTRACT

The differences in performance between three groups of Macintosh^{TM} computer users during word processing tasks was investigated: blind subjects using outSPOKEN^{TM} (a voice output program), sighted subjects using outSPOKEN, and sighted subjects using a word processor alone. The results indicated that blind and sighted subjects required similar time to complete tasks when both groups used outSPOKEN, but these same groups both differed significantly from sighted subjects using only the word processor. Other results indicated that the Keystroke-Level Model proposed by Card, Moran & Newell (1) is a good predictor of performance for both subject groups and both input methods, and that learning curve differences are determined more by input method than visual ability. The findings suggest that the increased cognitive load of using outSPOKEN may prevent blind Macintosh users from accessing the full benefit of the Macintosh user interface. They also suggest that the Keystroke-Level Model is a useful design tool for evaluating current and future screen reading software to be used by blind computer users.

BACKGROUND

Graphical user interfaces (GUIs) are here to stay. Their advantages have been documented and are widely accepted (2). But how easy are GUIs to use for computer users with blindness? This study compares blind and sighted Macintosh computer users performing word processing tasks. The access software used is outSPOKEN, a voice-output program that translates text, ions, windows, menu bars and dialog boxes into synthesized speech, and re-maps the numeric keyboard as screen navigation tools (Figure 1).

Three areas were investigated: differences in performance between blind and sighted computer users, the predictive ability of the Keystroke Level Model, and whether or not sighted subjects could be used, in certain situations, to test screen reading software.

Why are GUIs more difficult than text-based user interfaces (such as MS-DOS^{TM}) for blind users? Griffith (3) believes this is because spatially-oriented (2-D) visual information is being presented as linear (1-D) auditory information. The GUI environment is very complex, characterized as having five different classes of information or 11 different types of information (4,5). All this complexity requires an increased cognitive demand on the user, especially short and long-term memory (2, 6). This richness of information helps sighted users of GUIs, but makes it harder for blind users because it does not fit neatly into an auditory information display method (7).

This study measures the differences in performance, tests some methods of predicting the relative merits of screen readers, and explores different techniques for subject testing of screen readers.

The results of this research are of interest because GUIs, namely the Macintosh and MS-Windows^{TM}, are becoming the dominant workplace computer interface. In order for blind computer users to be competitive in the workplace, they will need access products which "level the playing field." The assistive technbology field will provide these access tools. It is incumbent upon us to provide GUI access which capitalizes on the advantages of GUIs without burdening the user.

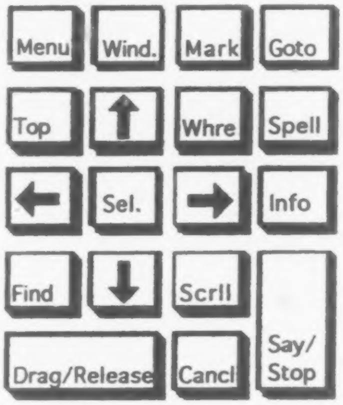


Figure 1. outSPOKEN Navigation Keys

RESEARCH QUESTIONS

1. Does OutSPOKEN allow blind users to keep pace with sighted users using standard word processing software?
2. Will the Keyboard-Level Model work reasonably well in predicting the time to complete tasks for all groups and methods?
3. Can sighted subjects be employed to test screen reading software?

METHODS

Subjects Twenty subjects participated in the experiment (14 women, 6 men, average age=39.8). They were divided equally into two subject groups: "Blind" (did not use their vision for computing, and "Sighted" (used their vision for computing).

Materials The experiments were run on an Apple Macintosh Classic computer with a Motorola 68000 CPU (7.8 MHz), 4 MB of RAM, System 6.07, and a built-in, 9-inch diagonal, monochrome, 512x342 display. The word processing program used was Microsoft Word™, version 4.0. The version of outSPOKEN used was 1.7. The voice settings for outSPOKEN were: speed (2), volume (3), and pitch (2). It should be noted that the speech speed was set relatively low (about 80 words per minute) so that inexperienced users would be able to understand the voice easily. An experienced user would have used a speech speed of 6 or 7, which equates to about 200 words per minute on this computer. When the sighted subjects performed the outSPOKEN tasks, the monitor was turned away from their sight.

Design and Procedure Two main analyses were performed. Analysis 1 was a series of planned comparisons of the task performance times of three treatment groups: Blind subjects using outSPOKEN (B/O), Sighted subjects using outSPOKEN (S/O), and Sighted subjects using the Standard method (not using outSPOKEN) (S/S). Analysis 1 was divided into three comparisons: C1: (B/O) vs. (S/S), C2: (S/O) vs. (S/S), and C3: (B/O) vs. (S/O). C1 related directly to Research Question 1, C2 was used as an experimental control, and C3 related to Research Question 3.

Analysis 2 looked at the ability of the Keystroke-Level Method (KLM) to predict the time to complete the tasks for the different groups. This related directly to Research Question 2.

All subjects followed set procedures for each task, which were developed with the assistance of an experienced outSPOKEN user to assure their validity. Advanced time-saving techniques, such as macros (pre-programmed sequences activated by simpler keystroke combinations) or "markers," (pre-defined locations which facilitate getting to a particular spot in a particular software program) were not used, although they most likely would be employed by full-time users of outSPOKEN (8, 9). Each task was completed five times sequentially, with short rests in between.

The six experimental tasks were various word processing activities, such as opening a document or selecting a sentence for editing. They varied in the type of task and the number of steps involved (5).

Randomization was utilized to control for the effects of order of task. Due to practical constraints, the two subject groups performed unequal total number of tasks (6 for the Blind group and 8 for the Sighted group).

RESULTS

All the analyses discussed in this section refer to the time subjects required to complete the tasks. Data are presented in three groups: Blind/outSPOKEN (B/O), Sighted/outSPOKEN (S/O), and Sighted/Standard (S/S).

For Analysis 1, the results showed that for C1 ((B/O) vs. (S/S)) there was a significant difference in time ($F(1,11)=352$, $p<<.01$), for C2 ((S/O) vs. (S/S)), there was also a significant difference in time ($F(1,10)=764$, $p<<.01$), and for C3 ((B/O) vs. (S/O)), there was not a significant difference in time ($F(1,14)=4.04$, $p>.01$). A graphical representation of the group means is shown in Figure 2. In this figure, the data is graphed showing the scores organized by the three study groups, and by their "means comparison circles" (10). If the circles touch or overlap, the means they represent are not significantly different. This corroborates the numerical results summarized above.

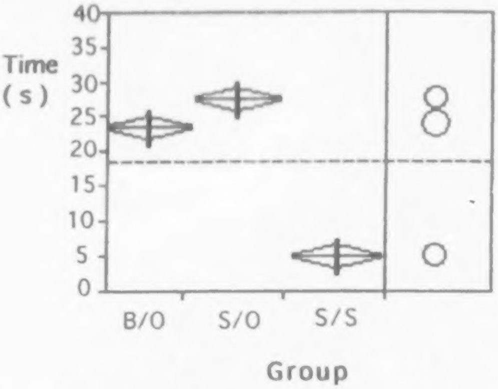


Figure 2. Graphical Representation of Group Means

These results show that B/O and S/O both took significantly longer to complete word processing tasks (using outSPOKEN) than S/S (using the Standard method) and that the differences between B/O and S/O were small. In other words, blind users using outSPOKEN could not keep pace with their sighted counterparts using the standard method in this experiment. This finding answers Research Question 1. In addition, blind and sighted users performed relatively similarly when both used outSPOKEN. This finding implies that, for situations similar to this experiment, sighted subjects may be used to test screen reading software (Research Question 3).

For Analysis 2, the results are summarized in Table 1.

Group or Method	R-square	F-value	p
Blind/outSPOKEN	.991	(1,4) 422	<.001
Sighted/outSPOKEN	.998	(1,2) 815	<.01
Sighted/Standard	.975	(1,2) 77	<.05

Table 1. Summary of Predicted vs. Actual Curve Statistics

These results tell us theat the KLM performed the best as a predictor for Blind subjects using outSPOKEN, performed second-best as a predictor for Sighted subjects using outSPOKEN, and performed Performance Differences Using outSPOKEN the "least-best" (although still respectably) as a predictor for Sighted subjects using the standard method. These results directly answer Research Question 2.

DISCUSSION

Using the Research Questions, what do the results tell us?

Q1: Does OutSPOKEN allow blind users to keep pace with sighted users using standard word processing software?

In the context of this experiment, the answer is a clear No. The take-home message is that if you want a screen reader program to be easy and quick to use, streamline the tasks as much as possible. The outSPOKEN versions of the word processing tasks required more steps (which takes more time) and it is also believed that the pause times between steps, (assumed to be "thinking time" (CNM)) were longer. Together these would put a greater cognitive load on the user, as suggested by Giffith (3). This experiment was not able to determine this hypothesis conclusively. Another difficulty encountered in this study was the issue of voice speed, macros and markers. Since the voice speed was set about 60% lower than experienced screen reader users would use, and macros & markers were not used, it is not known how much better the outSPOKEN users could have done. It is possible that these additional factors would have enabled the outPOKEN users to keep up with the standard method users.

Q2: Will the Keyboard-Level Model work reasonably well in predicting the time to complete tasks for all groups and methods? This model has been used to predict performance of computer users for over ten years. Although it may seem obvious to some that it would be a good way to predict the performance of screen reader users, this result may be a great help to developers of new screen reading software who wish to evaluate their new products. The KLM can be utilized economically and quickly prior to pre-release user testing.

Q3: Can sighted subjects be employed to test screen reading software? The results of this study say Yes. Taken alone, this may make testing of screen reading software easier. But it should be carefully noted that this statement is made only for experiments that are similar to this one. It is not known how this finding would hold up if the screen reading software was used in a more true-to-life configuration (faster voice speed and time-saving techniques). It would require that the sighted test subjects have more training to be able to get used to faster voice speeds, etc. This extra training for sighted subjects would then have to weighed against using experienced blind test subjects. It is hoped that this research will help developers of screen reading software to design and test their products.

REFERENCES

1. Card, S. K., Moran, T.P., Newell, A. (1983). The Psychology of Human-Computer Interaction. Hillsdale, NJ: Lawrence Earlbaum Associates.
2. Temple, Barker & Sloan, Inc. (1990). The benefits of the graphical user interface (Research Rep. No. 098-10794). Lexington, MA: Author.
3. Griffith, D. (1990). Computer access for persons who are blind or visually impaired: Human factors issues. Human Factors, 32 (4), 467-475.
4. Vanderheiden, G.C., Boyd, W, Mendenhall, J.H., Jr., & Ford, K.(1991) Development of a multisensory nonvisual interface to computers for blind users. Proceedings of the Human Factors Society 35th Annual Meeting (pp. 315-318). Santa Monica, CA: The Human Factors Society.
5. Vanderheiden, G.C. (1989). Nonvisual alternative display techniques for output from graphics-based computers. Journal of Visual Impairment & Blindness, 83 (8), 383-390.
6. Brooks, L.R. (1968). Spatial and verbal components of the act of recall. Canadian Journal of Psychology, 22 (5), 349-368.
7. Boyd, L., Boyd, W., Robinson, J., Sutton, M., & Berliss, J. (1992). Conditions for full access to the graphical user interface: Technical solutions and availability. Proceedings of the RESNA International '92 Conference (pp. 570-571). Washington, D.C.: RESNA Press.
8. Ford, K. (1991). A user's perspective on blind access to graphical user interfaces. Proceedings of the RESNA 14th Annual Conference (pp. 330-332). Washington, D.C.: RESNA Press.
9. Rubin. A., & Thuilot, D. (1991). Macintosh access for persons with blindness: A hands-on introduction. Symposium conducted at the meeting of ConnSENSE '93, Storrs, CT.
10. Sall, J., Ng, K., Hecht, M. (1989). JMP In (Computer Program). Cary, NC: SAS Institute, Inc.

ACKNOWLEDGEMENTS

Thanks to Alan Stewart & Richard Skov of Stevens Institute, Laurie Newman, my wife, Tom Anderson, John DeWitt, Jane Berliss of Berkeley Systems, Amy Rubin, John Noecker, Diane Thuilot and all study participants. Funding was provided by the Traineeship in Developmental Disabilities of the UAP of N.J., the Gaudet Fund of Stevens Institute, and the Hoboken, N.J. Lions Club. Berkeley Systems Inc. provided outSPOKEN during this study.

This paper was adapted from the author's Masters thesis, accepted May, 1994, at Stevens Institute, Hoboken, NJ. Please address correspondence to: Adam Krass, 113 Willow Terrace, Hoboken, NJ 07030 USA

VOICE-TACTILE INTERACTION FACILITATING BLIND USER ACCESS TO AN ADAPTED MULTIMEDIA RETRIEVAL APPLICATION

C. Stephanidis, P. Galatis, M. Sfyrakis and A. Koumpis
Institute of Computer Science, Foundation for Research and Technology-Hellas (FORTH)
Science and Technology Park of Crete, Heraklion, Crete, GREECE

ABSTRACT

This paper presents an experimental multimedia retrieval application, which addresses the interaction needs and requirements of blind users. The application has evolved from the adaptation of an existing experimental multimedia version, originally developed for sighted users, providing information about museum artifacts (traditional Cretan Pottery). Appropriate output devices have been employed to support alternative non-visual interaction methods. Preliminary experimental activities have been conducted during the design of the user interface, to identify the most appropriate presentation media and interaction techniques, as well as after implementation, to determine the effectiveness of the adopted approach.

BACKGROUND

The conventional approach, when developing or adapting text-based applications for blind users, is to provide textual data in tactile or auditory form. In the case of graphical environments, a number of commercially available solutions and prototype systems (screen readers) are currently used to enable accessibility to blind users (1), (2). These systems are based on the reproduction of the various graphical interface objects (such as windows, menus, icons, etc) into non-visual form, by utilising special purpose devices (e.g. Braille display, speech synthesizer, touchpad, etc). However, regarding adaptations of multimedia applications, additional issues need to be considered, due to the different presentational and behavioural characteristics of the associated interaction elements (e.g. video, animated graphics, non-speech audio, etc).

STATEMENT OF THE PROBLEM

The proliferation of multimedia applications poses new challenges for blind users: such applications impose concurrent manipulation of different types of information (e.g. text, audio, pictures, video, etc) and the utilisation of multiple input - output channels with emphasis on the visual one. Existing adaptation methods and available systems do not adequately address these problems, and therefore alternative methods and techniques need to be exploited when adaptations of multimedia applications are considered.

RATIONALE

The appropriate utilisation / combination of voice and tactile media for the representation (reproduction) of the different types of multimedia information may facilitate non-visual interaction for blind users. In this context, certain key issues related to the construction of non-visual interfaces for multimedia applications have been addressed, and preliminary observational studies have been conducted to determine alternative ways for facilitating blind user access to (adapted) multimedia applications.

DESIGN AND DEVELOPMENT

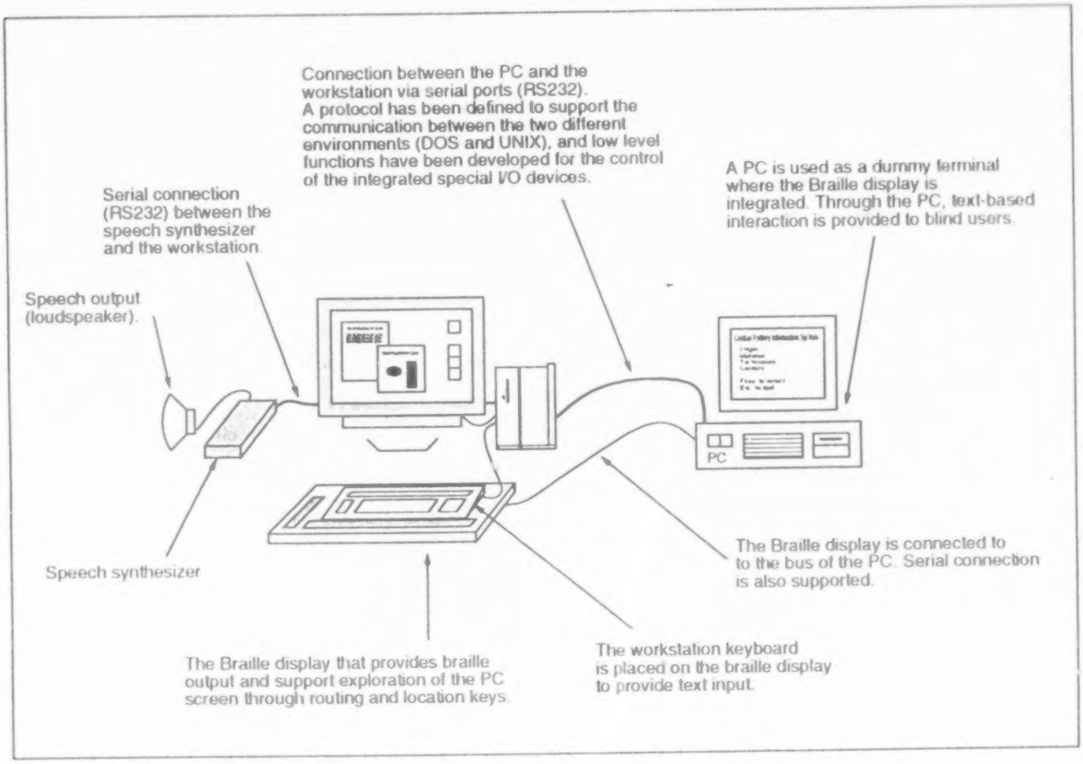
The user interface part of the graphical application was re-designed taking into account the particular needs, abilities and interaction requirements of blind users.

During development, modality- and device-specific modules have been incorporated, which utilise the available user communication channels (audio, motor and tactile) to support non-visual interaction patterns, and certain parts of the user interface of the information system have been re-developed utilising the audio and tactile modality.

A Unix Workstation was used as the base of the development platform. In addition to the standard I/O devices of the workstation, a speech synthesizer and a Braille display were used to provide auditory and haptic output accordingly. The Braille display was integrated in the workstation through a Personal Computer (PC), since direct connection to the workstation was not supported.

Utilising the functionality provided by the Braille display and the speech synthesizer, specific parts of the application's user interface have been adapted and reproduced in non-visual form. More specifically, the information selection (direct manipulation interface) and the provision of textual information have been reproduced in text-mode and are directed to the PC screen or the speech synthesizer. Browsing on the PC screen can be achieved either through the utilisation of the Braille display or, alternatively, through the use of a text-based screen reader. In order to provide consistency in the interaction for blind users, a set of rules have been adopted for the reproduction of the graphical interface modules. The selection menus and the textual information (regarding a specific object in the information system) are provided on the PC screen, while the messages from the application or messages regarding the navigation of a blind user through the various interface modules are provided in the form of audio messages.

As far as the reproduction of still or moving images is concerned, verbal description of the pictures, as they appear on the screen, is provided redundantly by means of prerecorded audio messages. Regarding the



Connection between the PC and the workstation via serial ports (RS232). A protocol has been defined to support the communication between the two different environments (DOS and UNIX), and low level functions have been developed for the control of the integrated special I/O devices.

A PC is used as a dummy terminal where the Braille display is integrated. Through the PC, text-based interaction is provided to blind users.

Serial connection (RS232) between the speech synthesizer and the workstation.

Speech output (loudspeaker).

Speech synthesizer

The Braille display is connected to to the bus of the PC. Serial connection is also supported.

The Braille display that provides braille output and support exploration of the PC screen through routing and location keys.

The workstation keyboard is placed on the braille display to provide text input.

Figure 1 - Adapted terminal emulator to support non-visual interaction

arrangement of the information or the selection menus on the PC screen, the screen is divided in two different areas. In the first area, the title and the available options of a selection menu, or the provided textual information for a specific object are displayed, while in the last row of the screen, information regarding the interaction can be provided. The user provides input through the keyboard. To facilitate blind user interaction, specific keys have been dedicated for specific actions. The description of a picture is provided on user request by pressing a reserved key, when the user accesses the associated object. Specific sounds or audio messages have been used to provide feedback to a user action.

Since the audio channel provides sequential access to information, parallel provision of auditory messages has been achieved through the classification in primary and secondary auditory information.

EVALUATION

In order to assess the effectiveness of interaction of the resulting non-visual user interface, some observational studies have been conducted where subjects were asked to accomplish a sequence of predefined interaction tasks and to fill-in a post-test questionnaire. These observations focused on the effectiveness of audio and tactile media in conveying textual, pictorial and vocal information, and the usability of the voice-tactile user interface to the multimedia retrieval application, in terms of consistency and comprehension of the interaction dialogue and the supported navigation procedures.

The observations provided valuable information regarding the presentation of the different media and the dialogue structure in interactive multimedia retrieval applications, useful for the development of voice-tactile interfaces. Some of the findings are summarised below:

- The use of multiple modalities does not necessarily improve the quality of the interaction dialogue.
- Speech seems the most natural medium for blind users, but tactile output in Braille form is considered more appropriate in the case of noisy or crowded environments, such as those found in offices, or when notational precision is required.
- The organisation/separation of the provided information can be assisted through the use of the appropriate medium/presentation for each different type of information, according to its purpose, nature, significance, etc.

BEST COPY AVAILABLE

- Still picture / video description, by means of a textual description of the image properties, is considered as rather poor. Alternative ways of presenting the pictorial properties need to be investigated.
- Parallel provision of information, instead of sequential access, is proposed as more suitable, if the provided items are not more than two or three, otherwise blind users might be overloaded or confused.
- The dialogue control should remain with the user. The application should not take "initiatives" without the explicit user's request.
- The user interface should be re-configurable during run time, so that different user preferences can be successfully supported. Moreover, since any adaptations are largely user dependent, knowledge of the target user characteristics and requirements is indispensable.
- Human-oriented tasks and new interaction metaphors should be utilised, if users not familiar with the technology are to be effectively supported.

DISCUSSION

An experimental multimedia retrieval system has been adapted and a voice-tactile interface was developed; preliminary tests were carried out to investigate low-cost and easy-to-implement solutions that provide accessibility to multimedia applications for blind users.

Issues which have been examined concern the presentation of the provided media in non-visual form, in terms of the *completeness* and *comprehension* of the presented information and the effectiveness of interaction through the developed non-visual interface in terms of the *efficiency*, *consistency* and *comprehension* of the dialogue, the navigation facilities and interaction possibilities offered to the blind user.

Currently, a more systematic evaluation of the developed system is under way to assess the usefulness and usability of the adopted adaptation approach.

ACKNOWLEDGEMENTS

This work has been carried out in the context of the IPSNI-II (R 2009) project, partially funded by the RACE Programme of the Commission of European Union (DG XIII). Partners of this consortium are: IROE-CNR, Italy; DUMC, United Kingdom; IRV, The Netherlands; CSELT, Italy; KUL, Belgium; Institute of Computer Science-FORTH, Greece; VTT, Finland.

REFERENCES

1. Weber, G., Kochanek, D., Stephanidis, C., Homatas, G., *Access by blind people to interaction objects in MS Windows*, in the Proceedings of the European Conference on the Advancement of Rehabilitation Technology, May 26-28, 1993, Stockholm, Sweden.

2. Emiliani, P. L., *Graphical User Interfaces for blind people*, in the Proceedings of the European Conference on the Advancement of Rehabilitation Technology, May 26-28, 1993, Stockholm, Sweden.

Dr Constantine Stephanidis
Institute of Computer Science
Foundation for Research and Technology - Hellas
Science and Technology Park of Crete
P.O. Box 1385, GR-71110 Heraklion
Crete, GREECE
Tel: +30-81-391741, Fax: +30-81-391740
E-mail: cs@ics.forth.gr

ENHANCING NON-VISUAL INTERACTION IN A GRAPHICAL ENVIRONMENT THROUGH A SCREEN READER CONFIGURATION SYSTEM

C. Stephanidis and R. Gogoulou
Institute of Computer Science, Foundation for Research and Technology - Hellas (FORTH)
Science and Technology Park of Crete, Heraklion, Crete, GREECE

ABSTRACT

There is a need to provide flexible and effective solutions that enable access to graphical environments by blind users. In order to address the particular abilities and preferences of blind users, it is necessary to support alternative interaction techniques and provide facilities which facilitate individualised configuration for non-visual interaction. This paper addresses issues related to non-visual reproduction of a graphical environment and presents a system for configuring the non-visual interface on the basis of blind users' needs and preferences through "easy-to-use" interactive facilities.

BACKGROUND

The need to overcome the accessibility problems posed to blind users by the proliferation of Graphical User Interfaces (GUIs), has led to a number of commercially available solutions or prototype systems (the so called screen reader systems). All of these attempts, which address the problem through adaptations, have mainly focused on the provision of mechanisms and tools which enable access to the various graphical interface elements (e.g. interaction objects, text within windows, etc) and reproduce the graphical information into non-visual form, by utilising existing special purpose devices (e.g. Braille display, speech synthesizer, etc) and/or by developing new devices which facilitate blind users' interaction in a graphical environment (1), (2), (3).

One important shortcoming of currently available screen reader systems is lack of facilities for customising the non-visual environment to the particular end-user needs and preferences. It is argued that, by providing support for alternative non-visual reproductions of the graphical environment and interactive facilities for selecting/combining the alternative non-visual interaction techniques, the capabilities of blind users to interact in a graphical environment can be significantly enhanced.

STATEMENT OF THE PROBLEM

Interaction in a graphical environment mainly concerns interaction with the various graphical objects (e.g. menus, buttons, windows, text, etc) and exploration of the screen contents. In this respect, it is necessary to enhance non-visual interaction by providing appropriate feedback to blind users, different navigational facilities and user-support mechanisms, as well as by meaningfully utilising/combining alternative output media for the reproduction of the graphical environment into non-visual form, according to the blind user's needs and preferences.

RATIONALE

Adaptation oriented approaches for the accessibility of graphical environments by blind users are based on the following general mechanism (2), (4), (5): (a) extraction/monitoring of data concerning the visual and behavioural features of the graphical applications; and, (b) reproduction of the extracted information into non-visual form. The non-visual reproduction can be based on the following approaches (3), (6): (i) the spatial representation of the screen contents, (ii) the hierarchical representation of the graphical interface objects, and (iii) both on the spatial and hierarchical representation. In any case, the non-visual interface should not only consist of a pure "rendering" of the graphical contents in non-visual presentation, but it is also important to provide alternative non-visual presentation modes and interaction techniques on the basis of different special purpose devices. The GUIB project has addressed, amongst other issues, the accessibility of the X Windows environment to blind users. In this context, we have developed the CONFIG system as a screen reader configuration system, to facilitate customisation of the non-visual environment.

DESIGN & DEVELOPMENT

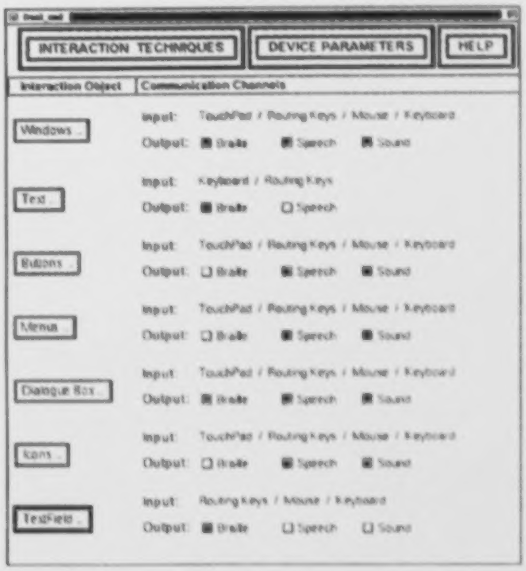
Adaptability of the user interface can be provided at various levels, such as the interaction dialogue, the structure/presentation of the user interface, the devices, etc. In this respect, the development of our

481

screen reader configuration system (CONFIG) has mainly focused on the provision of facilities which enable selection/combination of different non-visual interaction techniques and configuration of the utilised media, thus addressing the individual needs, abilities and preferences of end-users (blind users).

The system supports the specification of alternative output media for the various graphical interaction objects. An in-depth examination of the interface objects (i.e. both the presentational and behavioural characteristics of low-level lexical objects, such as windows, menus, etc) supported by the various graphical environments, and particularly those employed in the X Windows environment has been conducted, pointing out that: (i) it is not necessary to reproduce in non-visual form, some of the objects or object attributes; (ii) the utilised media determine the amount of information that need to be reproduced, resulting into different non-visual interfaces; and (iii) the combination of alternative output media can further enhance the quality of presentation of the interaction objects.

The output media which are supported for non-visual interaction include speech and non-speech auditory cues, and Braille output. Input operations (e.g. exploration/selection of menu options, etc) can be performed either by means of the standard devices (keyboard or mouse) or through special devices (i.e. mouse substitutes, touch pad and routing keys of Braille device). For each of the general classes of interaction objects (i.e. Windows, Text, Menus, Buttons, Dialogue Boxes, Icons and Text Fields), one or more of the incorporated output media can be specified, and subsequently the appropriate non-visual interaction techniques are supported (Figure 1). For instance, interacting with buttons, if speech, sound and braille output are used, the blind user can: (a) read through the Braille device the button label accompanied with a special character indicating sensitivity/insensitivity of the focused button; and (b) hear the button label and a special sound recorded to denote focus to a Button object.



Windows
Input: TouchPad / Routing Keys / Mouse / Keyboard
Output: ☒ Braille ☒ Speech ☒ Sound

Text
Input: Keyboard / Routing Keys
Output: ☒ Braille ☐ Speech

Buttons
Input: TouchPad / Routing Keys / Mouse / Keyboard
Output: ☐ Braille ☒ Speech ☒ Sound

Menus
Input: TouchPad / Routing Keys / Mouse / Keyboard
Output: ☐ Braille ☒ Speech ☒ Sound

Dialogue Box
Input: TouchPad / Routing Keys / Mouse / Keyboard
Output: ☒ Braille ☒ Speech ☒ Sound

Icons
Input: TouchPad / Routing Keys / Mouse / Keyboard
Output: ☐ Braille ☒ Speech ☒ Sound

TextField
Input: Routing Keys / Mouse / Keyboard
Output: ☒ Braille ☐ Speech ☐ Sound

Figure 1: A snapshot of the CONFIG system enabling the specification of the desired output media, for the supported classes of objects.

The configuration of the utilised media is performed by appropriately setting the associated parameters. For example, the system enables the specification of different speech parameters (e.g. language, voice) to be used according to the different modes of non-visual interaction (e.g. navigation in the graphical environment, interaction with menus, etc).

The system is implemented in the X Windows environment and consists of three basic modules (Figure 2):

1. the *translation mechanism* which appropriately interprets all the (media and device) settings, made by the user by interactively communicating with the CONFIG system, to low-level formal descriptions (i.e. in a format understandable by the screen reader).
2. the *dialogue editor* which supports the appropriate non-visual interaction techniques on the basis of the specified interaction and device parameters.
3. the *user interface* which provides "easy-to-use" interactive facilities for modifying the screen reader. The user interface of the system has been implemented on the basis of the Motif toolkit.

Additionally, the CONFIG system provides a general "HELP" facility regarding the use of the system; it also provides on-line help, which is interactively activated by pressing the right mouse button, for the seven classes of objects (Windows, Text, Menus, Buttons, Dialogue Boxes, Icons and Text Fields) describing their main characteristics as well as basic features of the non-visual interaction, by considering the available input/output media.

BEST COPY AVAILABLE

The CONFIG system supports flexibility concerning the inclusion of additional classes of objects (e.g. the "cursor" class which refers to other possible cursor types, etc) as well as of additional special purpose devices (e.g. speech recognition, touch screen, etc).

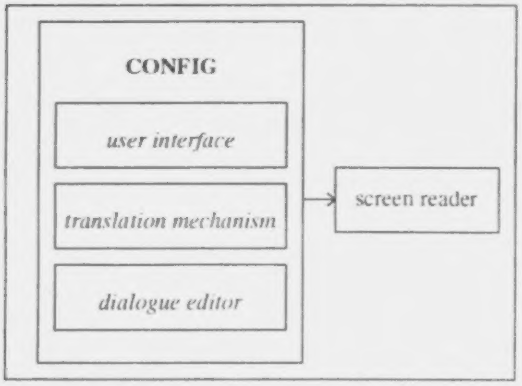


Figure 2: The three basic modules constituting the CONFIG system.

EVALUATION & DISCUSSION

The CONFIG system enables the configuration of the X Windows screen reader developed in the context of the GUIB project, according to the blind user's abilities and preferences.

The system has been tested by a small number of sighted and blind users in order to obtain a preliminary assessment of its usability. The initial comments have been, in general, very positive and encouraging and pointed to the overall usefulness of such a system. Sighted users (assuming the role of system supervisor) found it quite easy to interact with, and blind users (target end-users) acknowledged its usefulness and effectiveness in enhancing their possibility for non-visual interaction. Currently, more systematic (formal) methods are followed to evaluate the CONFIG system.

At present, the system supports customisation of the screen reader only at start-up time. Future activities will be directed towards the provision of the necessary means for adapting the non-visual environment also at run-time.

ACKNOWLEDGEMENTS

This work has been carried out in the context of the GUIB-II (TP 215) project, partially funded by the TIDE Programme of the Commission of European Union (DG XIII). Partners of this consortium are: IROE-CNR, Italy; Institute of Computer Science-FORTH, Greece; Vrije Universiteit Brussels, Belgium; Department of Computer Science-FUB, Germany; Institute of Telecommunications-TUB, Germany; IFI, University of Stuttgart, Germany; VTT, Finland; RNIB, England; F.H. Papenmeier Gmb & Co KG, Germany.

The authors wish to acknowledge the cooperative spirit of all consortium partners, the encouragement and support of the Project manager, Dr P.L. Emiliani, and the assistance of Dr G. Weber.

REFERENCES

1. Adams, F.R., Chery, H., and Jameson, D.H. *IBM Products for Persons with Disabilities.* In Proceedings of IEEE GlobeCom'89 (November 1989), 496-502.
2. TIDE-GUIB (TP 103) Deliverable No 5. *Analysis of Textual and Graphical User Interfaces*, (Brussels, December 1992).
3. Mynatt, E.D., and Edwards, W.K. *Mapping GUIs to Auditory Interfaces.* In UIST'92 (Monterey, California, November 15-18), ACM, 1992, 61-70.
4. Weber, G., Kochanek, D., Stephanidis, C., Homatas, G. *Access by Blind People to Interaction Objects in MS Windows.* In Proceedings of ECART 2 (Stockholm, Sweden, May 26-28 1993), 2.2.
5. Weber, G. *Adapting Graphical Interaction Objects for Blind Users by Integrating Braille and Speech.* In Proceedings of the 3rd International Conference on Computers for Handicapped People (Oldenbourg, Wien, 1992), 546-555.
6. Mynatt, E.D., and Weber, G. *Nonvisual Presentation of Graphical User Interfaces: Contrasting Two Approaches.* In Proceeding of the CHI'94 Conference on Human Factors in Computing Systems (Boston, Massachusetts, April 24-28, 1994). ACM, New York, 1994, 166-172.

Dr C. Stephanidis
Institute of Computer Science
Foundation for Research and Technology - Hellas
Science and Technology Park of Crete
P.O. Box 1385, GR-71110 Heraklion
Crete, GREECE
Tel: +30-81-391741, Fax: +30-81-391740
E-mail: cs@ics.forth.gr

SIG-12
Rural Rehabilitation

MOBILIZING ASSISTIVE TECHNOLOGY RESOURCES IN SOUTHWEST MICHIGAN

Sandra O. Glista, Department of Speech Pathology, Western Michigan University, Kalamazoo, MI
Carol P. McKnight, Van Buren Intermediate School District, Lawrence, MI
Patricia Winston, Kalamazoo Center for Independent Living, Kalamazoo, MI

ABSTRACT

In southwest Michigan, a primarily agricultural/rural region containing a population approaching one million people residing in nine counties, a collaborative, multi-agency, cross disability consumer effort is underway to problem solve methods for service delivery most pertinent to consumer identified assistive technology needs with the most economical and ecologically valid uses of available resources. Solutions identified and implemented thus far include the following:
1) establishment of a cooperative special educational regional enabling technology consortium;
2) implementation of a comprehensive evaluation protocol in special education school districts throughout the entire region;
3) establishment of an inter-agency collaborative task force for development of comprehensive regional services; 4) development of a community assistive technology council. A process for developing regional resources is described.

BACKGROUND

In many rural regions of the United States, access to assistive technologies, and especially alternative and augmentative communication systems and strategies is limited. Access may be restricted for many reasons including the lack of sufficiently educated/trained personnel locally available, limited availability of equipment for evaluation purposes, and insufficient funding sources to name only a few. While both centralized and decentralized models for rural access to assistive technology exist, individualized solutions to specific communities may prove to be the best alternative.

Individuals in southwest Michigan have significant unmet needs for a wide range of enabling technology services (Bahr, 1994). Using federal figures, at least 6% or 60,000 people of the region could be expected to have some enabling technology needs. This nine-county semi-rural region has barriers to acquiring enabling technology and related services despite its proximity to heavily populated urban areas such as Chicago and Detroit that have access to specialized rehabilitation services in large medical facilities. Even though resources existed in the region, it has been historically typical for persons with disabilities to either not receive assistive technology services or to travel outside the region for services. Barriers included, but were not limited to, lack of information about available resources and services, lack of funding, and lack of integrated services with educated providers.

In a comprehensive needs assessment of consumers from a wide variety of disability groups within the region, technology needs were prominently reported particularly in respect to repair of already purchased devices (such as wheelchairs), but also in accessing funding for purchase of equipment (Glista, et al., 1994). Consumers clearly identified the problems wishing for more and better trained providers, more locally available and affordable services, and more readily accessible funding for equipment (Glista, Erickson, & Davis, 1992).

Further, additional problems with service delivery existed in area public school systems. Identified problems included limited training of staff, lack of necessary equipment, and insufficient time for service including all aspects of evaluation, treatment, and teaching.

OBJECTIVES

Thus the following objectives were formulated: (1) to identify those agencies and individuals interested in technology service provision; (2) to convene task groups for problem solving and collaboration of effort; (3) to link existing regional resources; (4) to inform area consumers and providers of resources available regionally; (5) to formulate an action plan for closure of service delivery gaps. The ultimate goal was to instigate problem solving among people within the regional communities to share existing human and equipment resources; to become uniformly better informed about each others abilities and needs; and to mobilize those realizations into action plans for improved services to people with disabilities.

METHOD/APPROACH

Interested individuals, consumers, providers, agencies, and related groups were identified through a snowball sampling procedure. For example, special education administrators were made aware of the need for enabling technology collaboration by one of the authors (McKnight) who subsequently asked the administrators to solicit interested teachers and therapists to join the educational enabling technology consortium.

Similarly, author Glista, a Western Michigan University faculty member, invited key enabling technology providers to convene to discuss regional sharing of resources to better serve persons with disabilities. Those interested persons and agencies invited others to form the Southwest Michigan Enabling Technology Services Center task force. This group reviewed the findings of local, regional, and national disability needs surveys and decided to embark upon formation of a cooperative/collaborative service agency.

Finally, the third author, (Winston), acted as staff liaison for a consumer led Community Assistive Technology Council established under the auspices of the federal technology act granted to the State of Michigan, TECH 2000. As in the other instances, interested consumers, state case managers, providers, educators, and employers were invited to participate and to suggest others to join the group for meaningful dialogue.

In each group convened, the primary goals relative to assistive technology were sharing of information about already existing assistive technology services available, identifying problems in assistive technology, brainstorming solutions to identified problems, collaborating among groups for common problems and solutions, and finally implementing ideas.

Duplication of efforts was avoided through dual membership of several members on the various committees. Through this, information sharing was also enhanced.

RESULTS

The following are results of mobilization of these resources to date.

•Interested groups identified included providers and consumers from area Intermediate School Districts; Centers for Independent Living; Community Assistive Technology Council; Michigan Rehabilitation Services; Western Michigan University; Michigan Department of Social Services; and the Michigan Speech-Language-Hearing Association.

•Three separate groups convened to problem solve service delivery issues.

1. Thirteen Intermediate School Districts formed a regional technology consortium consisting of representatives from multiple disciplines. This task force consortium established a three year plan. In that plan, the following tasks have been accomplished in the first 18 months: created technology evaluation teams within each school district; wrote and disseminated a cross-disability assessment protocol for students from birth to 26; collected an inventory of all enabling technology products owned in the region; developed a lending/loaning system across the districts; educated personnel through inservicing newest methods and equipment; informed and educated administrators; and facilitated service delivery policy changes.

2. A Southwest Michigan Enabling Technology Services Center is under planning and development. Five major southwest Michigan agencies have come together to close service delivery gaps identified by consumers in a cooperative/collaborative model. Spearheaded by The Enabling Technology Center of Western Michigan University, a faculty research consortium, other agencies and organizations have joined to promote the development of a cooperative service system. The Kalamazoo Valley Intermediate School District, The Kalamazoo Center for Independent Living, Michigan State University Kalamazoo Center for Medical Studies, and Michigan Rehabilitation Services have all cooperated and contributed to the design of pilot project transdisciplinary service center. Currently seeking funding, the model program seeks to coordinate existing resources to maximize the ability of agencies in southwest Michigan to provide appropriate well-integrated interdisciplinary services. The model project will provide information, referral, training, evaluation and support to individuals and local service providers who have been unable to obtain comprehensive, coordinated, interdisciplinary services.

3. Representatives of community agencies and consumers convened to form the Community Assistive Technology Council sponsored by the Kalamazoo Center for Independent Living (KCIL) under the auspices of the State of Michigan TECH 2000 project. With a primary mission of disseminating information about assistive technology to the region, in its first year of operation, a Technology Day was held with over 150 attendees participating in workshops about equipment, service delivery, and funding. Further, the Council advised the KCIL in its compilation of an assistive technology data base and forecasted future service needs for persons with disabilities.

•Regional educational programming was begun with a visit by the Communication Aid Manufacturer's Association (CAMA) with an attendance approaching 200 providers and consumers.

DISCUSSION

The results of these endeavors have been positive. Bringing people together has offered opportunities for mutual collaboration and problem solving. Rather than looking to a centralized state level source or outside expert for solutions, local consumers and providers have cooperated to solve their own problems using their own resources. In addition to the actual products of each of the work groups, all individual participants have stated that a major benefit and outcome of their mobilization has been the networking provided by meeting with others throughout the region who are interested in or using assistive technologies.

Problems and frustrations of each of the groups have centered around, very simply, the amount of time that it takes for groups to conceive ideas, operationalize them, and then implement and carry out the action plans. More serious frustrations persist due to the ongoing inadequacies of funding and shortages of well trained service providers.

Future plans include continuation of all groups. The education focused regional technology consortium plans shared grant seeking activity, continuing education, and promotion of the benefits of enabling technologies for students. The Community Assistive Technology Council plans to create and adopt a marketing strategy during the next year to publicize the value of enabling technologies and also the availability of resources and services in the region. And the Enabling Technology Services Center plans to obtain funding and initiate service.

Additionally, the authors expect to repeat public education programs brought to the region, such as those offered by CAMA, to continue to link individual providers to regional interest groups, and to stimulate consumer peer support.

REFERENCES

Bahr, C. (1994). Assistive technology needs survey for consumers and service providers: Summary of responses. Unpublished manuscript.

Glista, S., Baker, B., Winston, P., Gaines-Summey, B., Meinhart, J., Burt, C., Hart, D., Noid, D., Hall, J., Olds, P., Potts, K., Jarvis, D., VanKesteren, G., & Maurer, M. (1994, April). Kalamazoo center for independent living consumer needs assessment report 1993-1994. Report to the board, Kalamazoo Center for Independent Living, Kalamazoo, MI.

Glista, S., Erickson, R., Davis, A. (1992, November). Community speech-language needs assessment. Paper presented at the annual convention of the American Speech-Language-Hearing Association, San Antonio, TX.

ACKNOWLEDGMENTS

Special thanks to all of the members of the Southwest Michigan Enabling Technology Services Center Committee, the Kalamazoo Center for Independent Living Community Technology Council, the District III Regional Technology Consortium.

Sandra Oslager Glista
Assistant Professor
Western Michigan University
Department of Speech Pathology and Audiology
Kalamazoo, MI 49008 U.S.A.
voice: 616-387-8064
fax: 616-387-8044
e-mail: sandra.glista@wmich.edu

COMMUNITY-BASED AND OUTREACH REHABILITATION: THE CANADIAN EXPERIENCE

Michael J.L. Sullivan, Ph.D.
Dalhousie University
Halifax, NS

ABSTRACT

This paper describes three main approaches to providing rehabilitation services to rural communities; 1) referral to an urban rehabilitation institution, 2) developing community-based rehabilitation resources, and 3) establishing out-reach rehabilitation programs. Advantages and limitations of each approach are discussed. The paper also addresses the need for more coordinated efforts in the development of effective strategies for rural rehabilitation service delivery. Current obstacles and future challenges are discussed within the context of rural rehabilitation service delivery in Canada.

BACKGROUND

With a geographical area spanning 10 million square kilometers, and apopulation of 26 million people, Canada ranks as one of the least densely populated of the industrialized nations. In Canada, prevalence rates of disability are approximately 15%, but may be as high as 20% in some rural communities (Statistics Canada, 1992).

In Canada, rehabilitation services are provided within the framework of a socialized health care system. By subsuming rehabilitation services within the framework of the healthcare system, Canadians with disabilities are guaranteed access to the medical management of disability related health problems. Although there are provincial and regional variations in the degree to which services are available, rehabilitation services are available without direct cost to the individual with a disability.

Rehabilitation services can be made available to rural communities in one of three ways; 1) individuals with disabilities can travel to urban institutions to obtain required services, 2) rehabilitation resources can be developed at the rural community level, and 3) rehabilitation services can be imported from urban centres to rural communities. Each option is associated with a distinct array of advantages and limitations.

Urban Rehabilitation Institutions. In the past, the first option was the only option for individuals with disabilities living in rural communities. The process of accessing rehabilitation services was frought with obstacles and inconveniences including long distance travel, extended periods away from home, and time loss from work. The individual seeking rehabilitation services could choose to tolerate the inconveniences or do without services; for many the latter was the most probable choice.

Aside from inconvenience, treating individuals from rural communities in urban centres has been discussed as inadequate as a method of rural rehabilitation service delivery. Providing rehabilitation services outside the environment that defines the disability places undue emphasis on the physical impairment component of disability and reflects a bio-medical view of disability that is no longer considered viable.

There are nevertheless advantages to providing rehabilitation services within urban rehabilitation institutions. Rehabilitation institutions permit access to a wide range of rehabilitation services, allow for multidisciplinary approaches to rehabilitation, and increase access to high technology services.

Community-Based Rehabilitation. One alternative to providing rehabilitation services within urban institutions is to develop rehabilitation resources within rural communities. In Canada, community-based rehabilitation in rural communities has been provided primarily through organizations such as Home Care, Public Health Nursing, or the Victoria Order of Nurses. Through these organizations, individuals with disabilities have access to attendant services, nursing services, meal preparation, physiotherapy, and occupational therapy.

The advantages of community-based rehabilitation over institution-based rehabilitation are apparent. Rehabilitation professionals within rural communities have a greater understanding of the physical and psycho-social demands of the rural environment than rehabilitation professionals from urban centres. Opportunities for ongoing treatment are maximized and the inconveniences associated with long distance travel are minimized.

The primary disadvantage of community-based rehabilitation concerns the limited range of rehabilitation resources that can be made available at the community level. There has been a general reluctance of rehabilitation professionals to establish themselves in rural communities, even when financial incentives are made available.

Out-reach Rehabilitation. Out-reach rehabilitation programs in Canada typically consist of teams of rehabilitation specialists, who are based in urban rehabilitation institutions and travel to rural communities to provide services. In a recent national survey, 17 out-reach rehabilitation programs were identified. The results of the survey indicated that out-reach rehabilitation programs were similar to rehabilitation institutions with respect to the range of disciplines represented and the types of populations served. But unlike rehabilitation institutions, the services offered by out-reach programs focused primarily on assessment, with minimal focus on treatment. The infrequency of clinic visits and time loss in travel place significant restrictions on the nature of treatment services that can be offered by out-reach programs.

One of the advantages of out-reach programs concern the direct ties they have with urban rehabilitation institutions. A substantial number of rehabilitation problems are sufficiently complex that they cannot be effectively managed by community-based services. The ready access to institutional admission may be an important option for individuals requiring intensive rehabilitation treatment or high technology services.

Some of the disadvantages of out-reach programs include the cultural differences between urban professionals and rural service providers. Negative attitudes toward city professionals can place significant barriers to effective out-reach service delivery. The efficacy of out-reach programs may also be compromised when treatment recommendations are made without an in-depth understanding of the limited rehabilitation resources available at the rural level.

Future Challenges. It appears that we have at hand the building blocks of a potentially comprehensive and cost effective system of providing rehabilitation services to rural communities. However, these are not terms that are typically used to describe the current state of rural rehabilitation services in rural Canada. A major problem has been that the development of rehabilitation resources for rural communities has not proceeded according to a national strategic plan. Rather, community-based and out-reach programs have developed in response to informal needs assessments and local initiatives. Consequently, there are wide disparities in the range of rehabilitation services available in Canada's rural communities.

What is urgently needed is a more coordinated approach to the development of rural rehabilitation services. Policy analysts have cogently argued that rural rehabilitation resources need to be developed according to an overall strategy within the broader context of the Canadian health care system.

A successful model of rural rehabilitation will need to incorporate features of community-based, out-reach, and institution-based programs. Community-based professionals will be necessary to allow for ongoing service provision at the community level, reducing the inconveniences of long distance travel, time away from home and work, and minimizing the potential of urban-rural cultural differences. Out-reach programs can be useful in providing specialized or high technology services that are unlikely to be available at the rural community level. Finally, rehabilitation institutions can be useful in providing intensive, multidisciplinary interventions that cannot be effectively provided with the resources available at the rural level.

ACKNOWLEDGEMENTS

This paper was prepared while the author was supported by grants from the Social Sciences and Research Council of Canada and Human Resources Development Canada.

Michael J.L. Sullivan, Ph.D.
Department of Psychology
Dalhousie University
Halifax, NS
B3H 4J1
Tel: 902-494-5177
Fax: 902-494-6585
Bitnet: SULLY@AC.DA.CA

SIG-13
Assistive Robotics and Mechatronics

THE DEVELOPMENT OF AN INTERFACE BETWEEN THE SPACEBALL™ 6DOF ISOMETRIC JOYSTICK AND THE MANUS REHABILITATION ROBOT

Andre Wisaksana*, Geb Verburg, Stephen Naumann
The Hugh MacMillan Rehabilitation Centre, Toronto, Ontario
***University of Toronto, Dept. of Mechanical Engineering, Toronto, Ontario**

ABSTRACT

This paper presents: (i) the Spaceball, a six degree of freedom isometric joystick as an alternative controller for the MANUS rehabilitation robot; and (ii) the design and development of an interface to enable direct communications between the two devices. A 6DOF isometric control scheme with force-Cartesian and torque-Euler angle mapping is used, which allows intuitive simultaneous control of arm position and gripper orientation in three dimensions.

BACKGROUND

Among the control devices used in rehabilitation, the most common one is still the two-axis joystick. Its main advantages are ease of use and ability to readily accommodate proportional control. The main restriction of this controller is that only devices with two or fewer degrees of freedom (DOF) may be controlled without mode switching. Mode switching remaps new output responses to the same set of inputs. Mode switching though common, does make device control more time consuming and less intuitive.

STATEMENT OF PROBLEM

MANUS is a wheelchair mounted rehabilitation robot. Six DOF are needed to control MANUS: three for position and three for orientation. The existing joystick control scheme uses a two-axis joystick in conjunction with a keypad and will require a minimum of three modes (3 modes x 2DOF = 6DOF). MANUS uses Cartesian x, y, z coordinates (z being the vertical direction) to denote arm position and Euler angles (roll, pitch, yaw) to denote gripper orientation. The two-axis joystick will allow intuitive control in the x-y direction but not for the remaining four DOF (z-direction, roll, pitch, yaw). Having to switch between modes during control also slows the process down.

PROPOSED SOLUTION

The Spaceball controller is a six DOF isometric joystick, and is shown in Figure 1. Instead of having to physically displace the control stick, as with traditional joysticks, the user instead exerts forces and/or torques to obtain the desired response. The control ball can sense forces and torques in three dimensions, resulting in six DOF. With Spaceball, the user receives resistance feedback instead of positional feedback. During normal operation, the user rests the base of the hand on the support, and the fingers/fingertips on the control ball. A function key, referred to as the pick button in the Spaceball literature, is located directly on the front of the ball; it is analogous to the mouse button. Within finger reach is an additional array of eight keys. The keys provide an additional nine degrees of freedom but are usually not used for real time control.

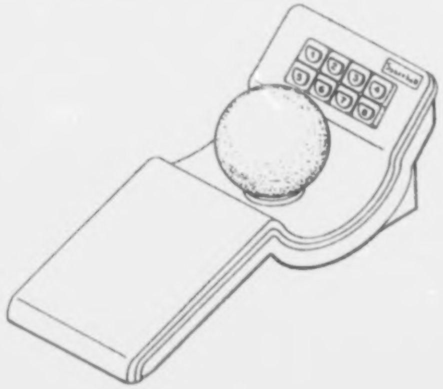


Figure 1. Spaceball

RATIONALE

The Spaceball offers an effective and intuitive means for controlling MANUS. It has previously been used to control object trajectory and orientation [5] in a virtual environment and was also used as a three dimensional controller at a virtual reality workshop at the University of Toronto this past fall. A client of The Hugh MacMillan Rehabilitation Centre who has cerebral palsy and some muscle spasticity also used the device and found it preferable. Given its ability for three dimensional control in the virtual environment, when similarly applied to the physical environment, Spaceball may well be a superior alternative to the two-axis joystick.

DESIGN AND DEVELOPMENT

SPACEBALL

The Spaceball controller has a built in microprocessor and communicates serially using an RS-232 port. The microprocessor allows the following Spaceball parameters to be configured to the user: null sphere, force sensitivity, torque sensitivity. The null sphere defines a common force and torque threshold, below which the Spaceball will not respond. The force and torque sensitivities may be set independently of each other. Spaceball may be configured by sending the appropriate commands over the RS-232 port.

MANUS

Spaceball's isometric control scheme makes proportional velocity control ideal for MANUS; this is most easily implemented using analog signals. Six analog signals are needed: three for arm position and three for gripper orientation. MANUS has an analog-to-digital chip (ADC) with seven available channels. The seventh analog channel is used for mode switching.

ADAPTICOL [2,3] is the MANUS control language. Patchboards are function routines, and a configuration consists of a set of linked patchboards. ADAPTICOL software was written to allow MANUS to be controlled by seven analog inputs.

The existing joystick control scheme uses the two channel DB-9 port in MANUS' control box. A circuit was built on the existing control card to access the additional five channels of the ADC via the DB-9 joystick port, resulting in a seven channel DB-9 joystick port. Another circuit of seven parallel potentiometers was built to send seven varying analog signals through the port. This circuit was used to test and debug the patchboards and configuration. The ADAPTICOL software written successfully allowed MANUS to be positioned and oriented using six analog signals.

INTERFACE DESCRIPTION

The interface uses a Motorola MC68HC705C8 controller. Communications between Spaceball and the interface occurs at 19.2 Kbaud. The maximum time between updates for analog signals controlling MANUS is 6.25ms (1 ms typical) and is fast enough for real time control.

Serial data packets from the Spaceball are translated by the HC705 controller and output as an eight bit number over an I/O port. The port connects to a ladder circuit which converts the eight bit number to an analog signal. This signal is sent to an amplifier and then to a demultiplexer under the control of the HC705; the demultiplexer outputs to each of the seven analog channels of MANUS' ADC. There is a sample and hold chip between the demultiplexer and each channel of MANUS' ADC, also under control of the HC705. The sample and hold chips maintain the analog signal level as the HC705 cycles through the seven analog signals.

When complete, the interface will allow MANUS to be positioned and oriented without having to switch modes. The interface will use the following input-response mapping scheme: Cartesian force vectors will directly correspond to the Cartesian velocity of MANUS' arm; the Cartesian torque vectors will correspond to the Euler angular velocities of roll, pitch and yaw. This mapping scheme is based on human hand motion, and will make real-time control of MANUS quicker and much more intuitive. Mode switching is needed to fold the arm in or out, and to open and close the gripper; the seventh analog channel will be used for this.

Other interface design features being implemented include configuration and damping routines in the HC705 software. The configuration routine will be accessed via the function keys: a sequence of key presses or a set of simultaneous pressed keys, whereby the null sphere, force sensitivity, and torque sensitivity may be custom set to user preference. The purpose of the damping routine is to compensate for muscle tremors/spasticity using a moving average scheme. As these are software modules, they will be easily implemented without the need for hardware modifications.

DISCUSSION

The Spaceball controller is also suitable for other rehabilitation devices, such as the more advanced powered chairs with tilt, seat raising or lowering, or omnidirectional capability [1]. It would however be impractical to have to build an interface for every device to be controlled. A solution using integrated control has been proposed by the M3S TIDE project. This involves using the Multiple-Master Multiple-Slave (M3S) [4] standard for all device communications; as all devices "speak the same language", only one interface will be needed. Making Spaceball's interface M3S compatible will be a direction for future work.

To conclude, who are the potential users? The ability to configure the null sphere, force sensitivity and torque sensitivity make Spaceball suitable for persons with weakness of the upper extremities and limited manual dexterity. The interface's moving average damping routine will allow persons with spasticity to use the Spaceball. Thus, Spaceball may be a useful controller for persons with muscular dystrophy, arthritis or cerebral palsy.

ACKNOWLEDGEMENTS

Funding for this project has been provided by the Ontario Rehabilitation Technology Consortium.

REFERENCES

[1] Helmut Hoyer, Ralf Hoelper, *Intelligent Omnidirectional Wheelchair with a Flexible Configurable Functionality*, RESNA Proceedings 1994, pp. 353-355.

[2] H.H. Kwee, M.M.M. Thönnissen, G.B. Cremers, J.J. Duimel, R. Westgeest, *Configuring the MANUS System*, RESNA Proceedings, 1992, pp. 584-587.

[3] Carol A. Stanger, *Using the MANUS Configuration Editor and Patchboard Editor*, A. I. DuPont Institute, University of Delaware, May 1994.

[4] J.A. van Woerden, J.C. Rosier, *Integrated Control of Mobility, Manipulation, Communication and the Environment*,RESNA Proceedings, 1992, pp. 575-579.

[5] Shumin Zhai, *Investigation of Feel for 6DOF Inputs: Isometric and Elastic Rate Control for Manipulation in 3D Environments*, Proceedings of the Human Factors and Ergonomics Society 37th Annual Meeting, 1993, pp. 323-327.

Contact:
Geb Verburg
The Hugh MacMillan Rehabilitation Centre
350 Rumsey Road
Toronto, ONT M4G 1R8, Canada
(416) 425-6220 ext. 529
email: verburg@ecf.toronto.edu

493

A VIRTUAL HEADSTICK INTERFACE FOR A MASTER-SLAVE REHABILITATION ROBOT SYSTEM

V. Jayachandran, D. Pino, M. Salganicoff, W. Harwin, T. Rahman, S. Chen
Applied Science and Engineering Labs (ASEL)
University of Delaware/Alfred I. duPont Institute, Wilmington, Delaware, USA

Abstract

This paper describes the implementation of a rehabilitation robot interface based on a "virtual headstick". The design philosophy is to develop an interface that has the same intuitive operation as a head or mouthstick but with greater flexibility and power. Design techniques have primarily focused on an interface for people with high level spinal cord injury but are also relevant to any disability where a person retains sensation but loses muscle strength. The design consists of finding the matrix transformations and control parameters required for implementing such a system. This paper describes the test bed, a breakaway mechanism for the user's safety, the forward and inverse kinematics of the PerForce™ robot, the Cartesian space position control system and the design and implementation of the virtual headstick.

Introduction

The Sensory Feedback project is investigating the effect of force feedback in helping a person better act on the environment through the aid of a robot. Another feature under study is whether proprioception can be used to improve control system performance. Part of this work involves developing a mouthstick analogue.

The mouthstick is a common and effective assistive aid used by people with spinal cord injuries. It is effective because it is in intimate contact with the human and hence conveys very good tactile information from the environment. It is also a good example of the significance of proprioception in contact tasks. A headstick can be equally effective, but is an intrusive assistive aid.

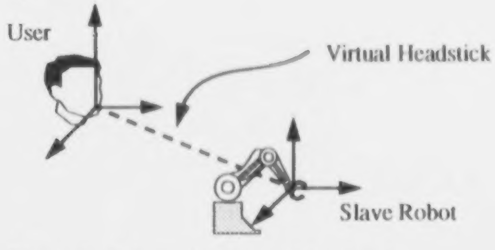


Figure 1: Schematic of virtual headstick

This has motivated us to test the effectiveness of our telerobot with a system that works on the same principle. This paper describes the design and implementation of a virtual extension of an individual's head movements (much like a mouthstick) using a telerobotic system which we call a virtual headstick (Fig. 1). We use this term because the end effector of the slave robot moves as if it were at the tip of an imaginary extension of the user's head. Also, the forces experienced at the slave are transformed and applied to the user's head by the master in such a way as to make him feel as if he were actually wearing a headstick and directly in contact with the environment.

Background

Most rehabilitation robotic systems rely on visual feedback as a means of finding out what the robotic arm is doing in the workspace. Unfortunately, constant visual attention can be fatiguing and may be of limited use in tasks with tight positional constraints (e.g. a peg in hole task). Alternatively, a force reflecting telerobotic system extends a person's proprioceptive and kinesthetic sensing abilities to the slave robot by sensing the forces in the environment and feeding them back in a resolved, useful form. In a similar manner, cable-operated prostheses and even simple mouthsticks take advantage of the user's intact proprioceptive and kinesthetic sensing abilities when manipulating objects in the environment. It is observed that control of manipulation tasks is much better when these forms of feedback, coupled with visual information, are available to the user.

To investigate the effects of sensory feedback on robot control, a test system has been set up which incorporates a force-reflecting head input device for individuals with high level spinal cord injuries. The head controller is electronically linked to the slave robot and contact forces sensed by the slave robot are reflected back to the user.

Description of System

The input is through a six degree of freedom master robot (the PerForce™ handcontroller manufactured by Cybernet Systems of Ann Arbor, MI) whose joints can be backdriven to apply forces at the user's head. The manipulation tasks in the environment are performed by a six degree of freedom slave robot (the Zebra-ZERO™ manufactured by IMI, Berkeley, CA) which has a force sensor at its wrist. The PerForce™ has been mechanically modified for control by the user's head movements (Fig. 2)

The forces picked up by the force sensor are transmitted to the master end where the data is transformed and applied as an appropriate set of forces on the user's head. The necessary computations are performed by two IBM PC-compatible computers which also handle bidirectional communication.

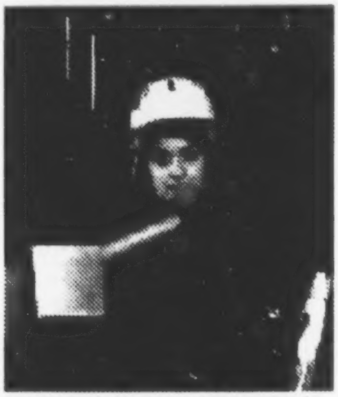


Figure 2: Picture of the test bed.

Magnetic Breakaway Mechanism

The intimate nature of interaction between the master robot and the user's head/neck make it of paramount importance that the system incorporate a reliable safety mechanism to prevent possible injury to the users. Even though software and electronic cutoff systems will be incorporated, it is important to additionally have a passive safety mechanism that instantaneously breaks away from the master robot when threshold forces are exceeded. The range of forces which can be applied by individuals with a high cervical spinal cord injury has been determined experimentally [2]. This data has been used as a baseline to specify threshold forces. The thresholds have been set by taking the intersection of the third and fourth quartile of the collected head range-of-forces data.

The design is innovative since it uses magnets as the restraining elements that break off when a certain combination of forces is applied (like a mechanical force fuse). The mechanism consists of two thin plates made of aluminum which have a combination of small magnets and flexible magnetic strips mounted on them. The combination ensures the mix of properties needed in the longitudinal and shear directions to accommodate the threshold force and moment specifications. The mechanism is mounted between the master robot and the helmet worn by the user. If the forces exerted by the master exceed the set thresholds, the lower plate breaks away and the physical link between the user and the robot is broken.

Kinematics of the PerForce™ Robot

The forward and inverse kinematics of the PerForce™ robot have been worked out since they are essential for specifying the system's configuration at any instant of time. The forward kinematics involve finding the position of the end effector for any set of robot joint angles. This involves finding a rotation matrix and a translation vector and has been done both by using geometrical methods as well as D-H notation[3]. The inverse kinematics involve finding all possible sets of joint angles for a given position of the end effector. For the geometry of the PerForce™, this gives one unique set of joint angles. The forward and inverse kinematics of the Zebra-ZERO™ have been provided by the manufacturers[4].

Cartesian Space Control

As a first step towards a general position control system, a cartesian control system has been set up on our test bed in which the slave mimics the translational motion as well as orientation of the master at any instant of time. The user puts on the helmet and finds a comfortable position. This position is sent to the slave as a reference and thereafter the two systems are activated and the slave's end effector translates and orients itself according to the motions of the user's head. The forward kinematics of the master are used to find the rotation matrix and translation vector that have to be enforced at the slave. The forces sensed at the slave are transformed into its fixed base frame and then communicated to the master where the joint motors are backdriven to apply forces on the user's head.

Design

The availability of the kinematics of both the master and the slave robot make it possible to implement any type of position control system that is desired. Since the link between the two robots is electronic and the force and position data that are collected are available for manipulation by the software, it becomes possible to transform the data to any form. Additionally, the system is modular and the kinematics of both the master and the slave do not have to be the same.

The headstick is the case when an extra imaginary link is added to the last joint of the master robot and an additional matrix transformation is necessary to determine the path that the tip of the imaginary link would trace if it were actually present on the robot. This information is then used to drive the translational motion of the slave's end effector. Due to the assumed rigid nature of the headstick, the orientation of the end effector remains the same as that computed in the case of cartesian control (Fig. 3).

DESIGN OF A VIRTUAL HEADSTICK

The forces that are felt at the tip of the headstick would cause moments at the head similar to the case of a mouthstick. The calculation of such forces has been done geometrically and shows up as a transformation which must be performed on the force data collected by the slave's force sensor before it is used for backdriving the master's joint motors.

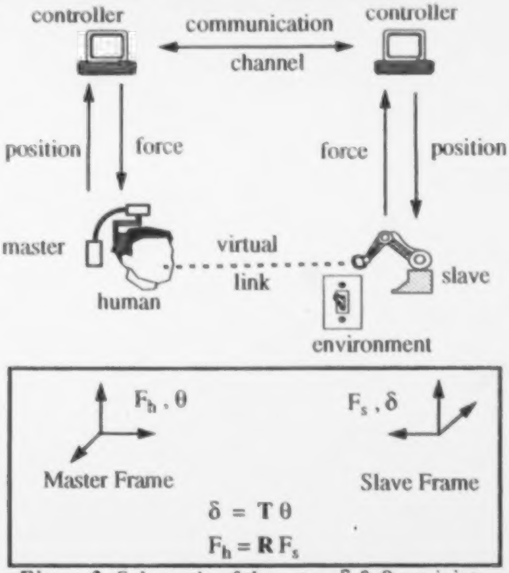


Figure 3: Schematic of the setup. δ & θ are joint *angles and* F_h & F_s *are forces.*

Performance Assessment Criteria

An ideal interface is one that is transparent to the user. This means that the user does not realize the existence of intermediate mechanisms or quickly learns to accommodate. Thereafter he feels as if he is directly in contact with the environment. Thus the sensation would be the same as that of wearing a real headstick.

Achieving such a system would involve a good choice of feedback gains to ensure stability of the system and to give a strong feeling of telepresence. Control system stability means that errors remain small even in the presence of moderate disturbances. Moreover, human beings get a sharp crisp feeling when they contact a hard wall but in telerobotics it is not easy to create such a feeling unless a judicious choice of feedback parameters is made[5]. A set of such parameters has been established for the test bed.

Testing

Since one goal of this research is to use proprioception to improve system control, the system's effectiveness in performing contact tasks has to be tested. The proposed tests include making the user trace the edges of rigid objects with the help of the virtual headstick. This could also be done with the user's eyes closed to see if the sensation is good enough for him to judge the shape of the object from force feedback alone. Another feature of proprioception is the ability of human beings to retrace a path with their eyes closed. Hence a test would be to make a person visually guide the headstick to a point, retrace to the starting position and then go back to the same point with closed eyes.

Conclusion

This paper presents a way of controlling a rehabilitation robot with force feedback by using a virtual headstick on a telemanipulation system. Advantages of such a system include power amplification, extension of range of motion and better control due to force feedback while maintaining an intuitive interface.

References

[1] T. Rahman, W. Harwin, S. Chen, R. Mahoney, R.Glass, D. Pino. Rehabilitation robot control with enhanced sensory feedback. In *Proc. of the Fourth International Conference on Rehabilitation Robotics, Wilmington, DE 1994.*

[2] Carol A. Stanger, Annezio C. Phalangas, Michael F. Cawley, M.D. Range of head motion of high cervical spinal cord injured individuals for the design of a test-bed robotic system. In *Proc. of the Fourth International Conference on Rehabilitation Robotics, Wilmington, DE 1994.*

[3] John J. Craig. *Introduction to Robotics - Mechanics and Control, 2nd Ed., 1989.* Addison-Wesley Publishing Co., Inc, Reading, MA.

[4] Zebra ZERO user's manual, Integrated Motions, Inc.

[5] B. Hannaford. A design framework for teleoperators with kinesthetic feedback. *IEEE trans. on Robotics and Automation, vol 5, No.4, Aug 89.*

Acknowledgments

The authors gratefully acknowledge support from the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant# H133A20001 and Nemours Research Programs. The work was carried out at the Rehabilitation Engineering Research Center for Robotics.

Author address

Vijay Jayachandran
Applied Science and Engineering Labs
Alfred I. duPont Institute
P.O.Box 269, Wilmington, DE 19899
Phone: (302) 651 6830 / Fax: (302) 651 6895
email: *jayachan@asel.udel.edu*

A SENSOR-BASED MANIPULATION STRATEGY FOR APPLICATIONS IN REHABILITATION ROBOTICS

W.A. McEachern, R.D. Jackson
Department of Engineering, Cambridge University, U.K.

Abstract

This paper presents research into sensor-based shared control of a robotic manipulator for rehabilitation applications. The manipulation strategy is identified, and its implementation in a simulated environment is described.

Background

Manipulation aids for the severally physically handicapped can currently be classified into the following categories: wheelchair based manipulators [4,7], mobile robot manipulators [9], and fixed, workstation based systems [2,5,6,8,10]. In general, wheelchair based and mobile systems operate with some form of direct control, where the user directs each motion of the manipulator in joint or world space co-ordinates. Workstation based manipulators operate in an at least partially defined environment, and hence can employ pre-programmed actions, but still tend to include the option of direct control to improve the flexibility and robustness of the system.

Much research in industrial teleoperation is being directed towards shared and supervisory control architectures which allow for some remote control and automation of tasks. The relatively new field of computer-aided teleoperation attempts to combine approaches in traditional robotics research with teleoperation, that is, to develop robotic manipulators which retain the human operator in the control loop. Standard industrial teleoperation applications thus have a great deal in common with those of Rehabilitation Robotics. In particular, in each field we find applications which involve the use of robotic manipulators to perform a wide variety of low volume, non-repetitive tasks. Differences in the strategies used to control rehabilitation robotics manipulation systems arise due to the disability of the operator, and the potential for the operator to be present in the working envelope of the manipulator. Nevertheless, many of the same challenges arise in each field, and similar techniques may be appropriate to their solution.

The Cambridge University Robot Language (CURL) [1] has been specifically designed for rehabilitation purposes. CURL provides task, command and direct level control, and in this work will ultimately be used to generate the primary manipulator trajectories which are modified using the sensor-based algorithms.

Statement of the Problem

This research has identified the need for a flexible manipulation strategy which shares control of the manipulator between the intelligent system and the user. The purpose of shared control is to augment the perception and manipulation capabilities of the user without completely removing control from them. Thus, the manipulation strategy relies neither on direct control by the user, nor the complete definition of the working environment. Such a strategy must incorporate adequate sensing capabilities and autonomy to enable the system to perform skills such as obstacle avoidance and intelligent grasping in real time, and hence relieve the user of a significant amount of the burden of control and planning. The main focus of this research is the development of methods of incorporating sensor data and a priori knowledge with user input, and consequently resolving conflicts between the goals of the user and those of the system. Research in this area is not only useful in the development of a general purpose manipulation aid but can also be helpful in increasing the robustness and flexibility of existing systems through novel approaches to sensor integration and manipulator control.

Approach

Trajectory Modification Algorithms

The structure of the manipulation strategy has evolved to a form very similar to that described by the co-ordinative control programme of human motor control [3]. The advantage of using this structure in a robotic application arises from the assumption that sensory input from the environment can be used to modify a movement, without the restriction that the movement must be totally reliant upon it. Additionally, complex motor programmes can be built up from their fundamental units without the need for complete pre-programming of tasks.

The architecture used to implement the trajectory modification algorithms consists of a number of 'behaviour-generating modules' each with a specific

497

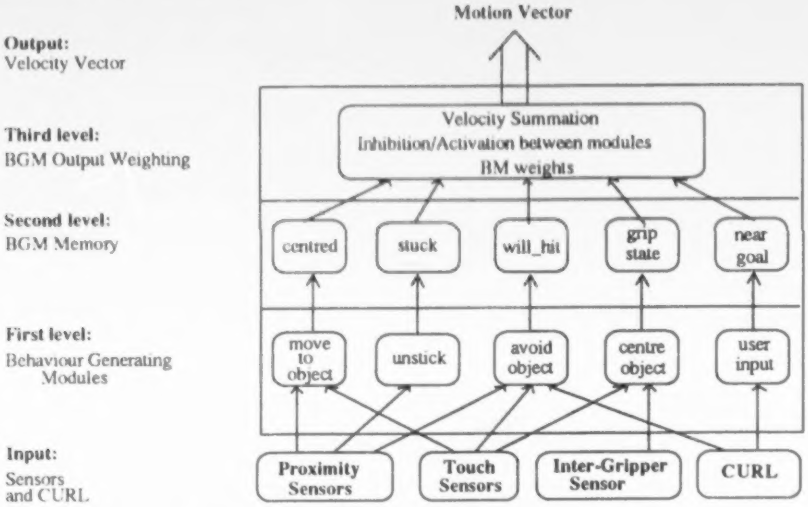


Figure 1. Structure of the manipulation strategy.

competence and output independent to that of the other modules. The input to each module is sensor information, and the output is a velocity vector consistent with the behaviour of the module. For instance, proximity information is used by the 'Avoid Objects' behavioural module to generate a velocity in the opposite direction to sensed objects in the robot's path. The velocities from these modules are then weighted and summed using the output weightings defined for the current task.

As shown in figure 1, the architecture is a three-level system. At the lowest level, the behavioural modules generate completely reactive outputs given the state of the relevant sensors in the current time frame. At the second level, some 'memory' is employed to determine the appropriate weightings to be applied to the outputs of the individual modules. For example, the probability of an object being in the path increases with the number of samples in which it is detected, so the output of the avoid object module is weighted appropriately to reduce the sensitivity to noisy sensor readings. At the third level, activation and inhibition between behaviours occurs. The third level is the only point at which interaction between the modules takes place, and is consequently where any 'intention' or task-orientedness can be implemented. The interaction between behaviours is both hard-wired and flexible. That is, the form that the interaction will take is hard-wired, but the degree to which the interaction will take place depends on the task-oriented parameters passed to the trajectory modification algorithms by CURL or an equivalent trajectory generating program. Thus, each of the defined behaviours will always be present, but their significance is determined by the context of the motion.

Simulation of the Robotic System

The sensor-based movement algorithms have been developed and tested in simulation. A simulated environment can not be considered a complete test of any system due to the richness and diversity of the real environment, which the programmer can not hope to duplicate. However, simulations can be a valuable tool in the development of a robotic manipulation system; they give the flexibility to undertake testing of the system under a diverse range of conditions, without large set-up time or cost, and without danger of damage to the hardware, or to the user. The ability to test the movement algorithms using different robots, different environments, and different sensor configurations was of particular interest to this research.

A simulation of a sensor-equipped robot was developed in the commercial package, Workspace 3.2. Workspace allows for the definition of complex three-dimensional environments and robotic systems. Using Denavit-Hartenberg matrices it is possible to define robot kinematics, and simulate motion in a 3D environment at a joint, actuator or Cartesian control level.

Robot programs, called 'tracks' are written in the interpreted robot language, Karel, and can be linked as a dynamic link library (DLL) with Pascal procedures for greater functionality and speed. In order to test the sensor-based algorithms, simulations of proximity sensors and of touch sensors were written for the Workspace

498

environment. Due to speed considerations, the sensor simulations are currently limited to interaction with blocks. However, as all primitive Workspace objects are defined in terms of planar approximations, it could easily be expanded to other geometries if desired.

After a Workspace environment has been defined, it is possible to read the location of the vertices of a defined object, move or rotate the objects, and move the defined robot in a joint or Cartesian frame. The movement algorithms have been written to operate with no knowledge of the environment other than what can be obtained from sensors, whether in Workspace or a real environment. Hence, knowledge of the Workspace environment is used only for the sensor simulation, and not directly in the motion planning.

Results

Numerous trials in a variety of Workspace environments were carried out in order to refine the behavioural modules and their interactions. One frame of a typical trial is shown in figure 2. The robot is given the approximate co-ordinates of a goal or an object and the context of the task is indicated. For example, in the trial shown in figure 2, the robot is told the approximate location of the small block, and that the objective is to pick up the block. In general, if the given co-ordinates are such that the robot detects the object in the course of its movement, it is able to complete the task. The robot is equipped with eight infrared sensors, and two touch sensors on the end-effector.

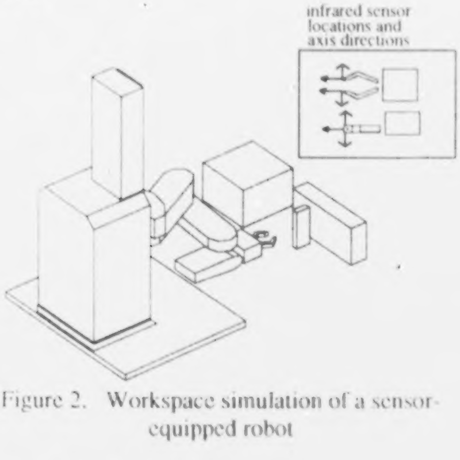


Figure 2. Workspace simulation of a sensor-equipped robot

Discussion and Further Research

This paper has presented a modular, flexible strategy for the modification of manipulator trajectories based on sensor information. The algorithms combine simple, independent behaviours to build up more complex, intelligent-seeming behaviours. Task-orientedness is accomplished by weighting the existing behaviours in a manner which reflects the behavioural composition of the task. A simulation of the robotic system was used to show the viability of these techniques. Further research will include implementation of the system in hardware, and the integration of the trajectory modification algorithms with CURL. Testing of the system in a real environment will then be undertaken.

References

[1] Dallaway, J.L., et al, An Interactive Robot Control Environment for Rehabilitation Applications, *Robotica*, vol. 11, 1993, pp. 541-551

[2] Hillman, et al, A., User Aspects in the Design of a Robotic Workstation for the Disabled, *ECART 1990 Proceedings*, The Netherlands., 12.2

[3] Jeannerod, M., The Neural and Behavioural Organization of Goal-Directed Movements, Oxford University Press, 1988.

[4] Kwee, K.H., Duimel, J.J., The Manus Wheelchair-Borne Manipulator, *ECART 1990 Proceedings*, Maastricht, The Netherlands, 12.3

[5] Mahoney, R., The Design of Interactive Robot Workstations, Cambridge University Engineering Dept. Internal Report, June, 1991

[6] Masanic, C., et al, Task Command Language Development for the UT/HMMC Robotic Aid, *RESNA 13th Annual Conference*, 1990, pp.301-302

[7] Prior, S.D., A Survey of Potential Users of an Electric Wheelchair Mounted Robotic Arm, *RESNA 13th Annual Conference, 1990*. pp.297-298

[8] Pullin, G.,et al, Further Development of a Robot Workstation for the Disabled, *RESNA 14th Annual Conference*, 1991, pp.21-22

[9] Regalbuto, M.A., et al, A Framework for a Practical Mobile Robotic Aid for the Severely Physically Disabled, *RESNA 13th Annual Conference*, 1990, pp.127-128

[10] Valettas, N., Goldenberg, A., Milner, M., The UT/HMMC Robotic Aid, *RESNA 12th Annual Conference*, 1989, pp.111-112

Wendy McEachern
Engineering Department, Cambridge University
Trumpington St., Cambridge, CB2 1PZ, U.K.
email: wam@eng.cam.ac.uk
Tel: +44 223 332754
fax: +44 223 332662

A COMPOSITE PROXIMITY SENSOR ARRAY FOR MOBILITY AIDS

Angelo M. Sabatini, Vincenzo Genovese, Eugenio Guglielmelli, Paolo Dario
Advanced Robotics and Technology Systems Lab (ARTS Lab)
Scuola Superiore Sant' Anna
Pisa, ITALY

ABSTRACT

Recent technological advancements promise that a new generation of mobility aids endowed with sophisticated navigational capabilities are about to be available, for helping patients affected by severe physical disabilities in safely performing purposive motions in their environments. For achieving this goal, one important technological challenge concerns how to improve the functionality and reliability of the sensorial systems to be used by the mobility aid.

In this paper, we propose a novel approach to the design of proximity sensor arrays. The approach relies upon the concept of the composite sensor, or skin receptor, e.g., a device resulting from the integration of ultrasonic and infrared transducers in the same sensing element. Because one of the most relevant advantages of using such proximity sensors is in their low cost and simplicity of use, the choice of the components and the firmware design of the proximity sensor array should not determine significant shifts in the cost/performance ratio, compared to the products already available on the market. These issues are addressed in the paper, with regard to sensorization of an electric wheelchair.

BACKGROUND

The use of multiple, overlapping, low resolution proximity sensors and the integration of the information they supply are a widespread means to cope with the spatial uncertainty of unknown, unstructured environments in the field of advanced robotics. Several areas of relevant interest in rehabilitation engineering may also benefit from advancements of the state-of-the-art in the related sensing technologies; potential applications concern the development of autonomous robotic servants, advanced wheelchairs with navigational capabilities and orientation aids for visually impaired people. The integration of sensors, computing devices and hierarchical control systems that are necessary for giving a mobility aid a sort of navigational intelligence are about to change their traditional concept. One of the key points involves, in our view, the sensor technologies and the methodologies of sensor integration/fusion which must be used in the design of the navigation system.

Obstacle detection and avoidance is, of course, an important skill any mobility aid should be able to perform. In-air ultrasonic (US) transducers and infrared (IR) sensors are widely used as proximity sensors for accomplishing the detection task. The complementary features of reflecting behaviors for US waves and IR radiation in air make interesting the perspective to fuse together the information they supply for achieving a robust and reliable behavior of obstacle avoidance. However, research prototypes or commercially available robotic systems that integrate US and IR proximity sensors are quite the exception than the rule [1]. The reason is partly that in most cases the IR sensors can be used just in an on-off fashion, so that the possibilities to perform sensor fusion in a true sense appear quite limited. Recently, we proposed the concept of a composite sensor, the "skin receptor" (SR), e.g., a sensor which results from integrating different proximity sensors, namely a pair of US transducers (the emitting and the receiving capsules) and an IR detector (the light emitting diode and its coupled photodiode). A number of these composite sensors may be arranged in any appropriate configuration, so as to define ring-like proximity sensor arrays for applications in the field of autonomous mobility or multisensor linear arrays for accomplishing tracking/docking tasks [2].

In this paper, we describe the approach to the design of arrays of composite sensors we are pursuing within the context of the EC TIDE project OMNI [3]; the aim of the project concerns the development of an omnidirectional wheelchair with navigational "intelligence". The wheelchair is intended to assist patients, even patients with severe mental handicaps, in their efforts to move within relatively unstructured, indoor environments. A limitation that users of traditional wheelchairs experience, particularly when moving in cramped spaces, concerns the need to rotate the wheelchair before changing direction. In order to overcome this problem, the OMNI wheelchair employs the Mecanum wheels, so that the user is allowed to move in any direction, without prior rotation [4]. Additionally, an intelligent and flexible configurable control system has been proposed, which is able to integrate high-level functionality and low-level control. The integration of sensing systems within the control structure of the wheelchair should allow, in principle, to expand its functionality and to provide the capability of controlling it by the user at different levels of abstraction. Within the consortium, our group is mainly involved in the design and fabrication of the sensorial system the wheelchair will be equipped with; our involvement is also in the design of the navigation module for implementing the "reflex" of obstacle avoidance.

RESEARCH QUESTIONS

Most current US systems are of the pulse-echo type, namely they work according to the time-of-flight (TOF) principle of operation: an US pulse is emitted by the transmitting transducer and the time elapsed between transmission and reception of the reflected signal at the receiving transducer is measured; if the speed-of-sound value is known, the TOF quantity can be easily converted into range information. Because of the typical specular nature of the US waves reflection, only reflecting objects that are almost normal to the sensor acoustic axis may be accurately detected.

Most current IR systems are based on on-off detection of the back-scattered radiation, after that a high-intensity light pulse is transmitted outwards. As a rule, no attempt is made to exploit the peak amplitude of the return signal for distance estimation purposes, because of its sensitivity to the reflectance properties of the objects. Although IR proximity sensors do not provide directly an estimate of the distance between the transducer and the reflecting object, many obstacles which might be invisible to US sensors can be detected by means of IR sensors. This is because IR sensing is minimally sensitive to the object orientation unless the inclination angle is very large.

A composite sensor is capable, in principle, to achieve a perception of the explored objects which is not necessarily limited to their geometrical properties (size, shape and location relative to the sensor); Additionally, the perception may be extended to other relevant features. Provided that the range estimation comes from the US sensor, we can exploit, for instance, the fact that the IR output depends on the reflectance of the object to achieve a sort of chromatic characterization of the object. For the above-mentioned reasons, a combination of US and IR sensors sounds appropriate for designing proximity sensor arrays. Sensor fusion techniques must then be included in the navigation system in order to manage the different kind of information coming from the sensors.

METHOD

Our approach to the design of redundant proximity sensor systems is based on the assumption that the use of expensive transducers and complex signal processing techniques must be avoided if we desire a better cost/performance ratio compared to that of more sophisticated imaging systems, such as the ones based on stereopsis or laser scanning. The sensing elements we use are low-cost, off-the-shelf components. The attention towards the "cost" factor is also reflected in the choice of the processors needed for complying with the expected computational requirements. The proposed sensory system employs in fact an embedded, distributed microcontroller-based architecture; a single, low-cost, 8-bit microcontroller is sufficient to control an array of up to 16 SRs. Also, the proposed architecture offers the way to perform signal acquisition and limited sensory data pre-processing.

An industrial PC board forms the "hearth" of the navigation system, namely the computing engine where sensor fusion and map building are performed. The output of the navigation module is delivered as a velocity vector; the higher levels of motion planning and control of the wheelchair are thus informed where and how fast it would be safely steered, compared to the actual direction and velocity of motion.

The microcontroller-based architecture provides the system with a high degree of flexibility and modularity; if necessary, an "upgrade" might become possible, by placing more sensors within the array. Additional sensors may be helpful for tracking beacons in the environment, in the attempt to correct the calculated position/orientation of the wheelchair or for accurate back-tracing of the followed path; the sensor data from these beacons integrate the dead-reckoning system actually used by the motion control module of the OMNI wheelchair.

RESULTS

Given that the computational capabilities of our microcontroller-based architecture are limited, we cannot afford the luxury to resort to extensive and sophisticated numerical processing for filtering the signals from the SRs. Hence, a great deal of efforts have been spent in the attempt to extract the desired information from the sensors in a robust manner by means of a careful design of the analog circuitry. This is also motivated by observing that both the sensitivity of detection and the measurement accuracy of US and IR sensors critically affect the amount of information they convey. For the analog part of the US subsystem, we have introduced a novel TOF estimator that, under the assumption of echo shape invariance, produces unbiased estimates whose accuracy is almost independent of the amplitude fluctuations at the receiver. The sensitivity to amplitude fluctuations is one of the major drawbacks of classical threshold-based detection methods and a reason for making quite inaccurate the incoming data. The proposed detection method requires that the

501

integral of the received signal envelope is compared to the envelope itself in the attempt to localize in time the desired information [2].

One of the most important problems when dealing with proximity IR sensing technologies is represented by the limited measuring performances (sensitivity, accuracy and resolution) which are achievable by means of off-the-shelf components and sensing elements. Given our present interest for low-cost proximity sensor arrays, costly optical lenses or other devices that are useful for collimating the beam were discarded. A synchronous, double integration of the received signal has proven a valuable device to improve the performances of pulsed-excitation systems in terms of achievable maximum sensing range [2]. Compared to continuous wave systems, the greater efficiency of traditional pulsed-excitation systems is counterbalanced by a much greater sensitivity to noise, given their wider bandwidths. The desired signal is finally extracted by differencing the two analogue values resulting from the double integration through a cascade arrangement of four differential amplifiers with increasing gains, in order to have an extended output range. This solution provides a high sensitivity within an output range which is still compatible with the input range of the A/D converters of the microcontroller-based control unit.

According to the results of the calibration procedures, the proposed TOF estimator results unbiased, with a standard deviation which is almost constant over the domain of interest ($\sigma \approx 2$mm, $D_{max}=2$m). The IR detector output depends on the sensor-target distance in a non-linear fashion; because of the limited resolution of the A/D conversion system available on the microcontroller, the resulting range measurement resolution is worse compared with that of US sensors. The detection method has proven to be quite insensitive to most common disturbances that are known to plague IR detectors in typical household environments. We observed that the sensor output is strongly dependent on the reflectance properties of the object. The maximum sensing range, obtained in the best conditions of planar, white targets, is in the order of about $D_{max}=50$cm. Consequently, each composite sensor in our current implementation of the system may offer the way to characterize the target in terms of its reflectivity, once the range data are provided by the US sensor.

DISCUSSION

The approach to the design of proximity sensor systems we are currently pursuing concerns the integration into the same system of different sensing modalities in the attempt to overcome the limitations of each by performing sensor fusion. A great care is taken in the various steps of the design and fabrication process to preserve the most appealing advantages of using US and IR sensing technologies, namely their low cost and simplicity of use.

The sensorial system in its hardware/software components is ready at the time of writing this paper. Currently, we are proceeding towards the next move, namely how to use the information from both types of proximity sensors in order to accomplish specific functions. One of the problems we are currently dealing with concerns a) the characterization of the reflecting objects in terms of their reflectance properties, using methods from the decision theory and b) the robustification of histogrammic methods for obstacle avoidance. These methods typically require to consider just one type of range sensing modality, e.g., the US sensors; we are investigating how the information from the IR sensors may contribute to improve their robustness.

REFERENCES

[1] TRANSITION RESEARCH CORPORATION, Inc.: 'SonaRanger™ Proximity System: Technical Specifications', Danbury, CT, U.S.A, 1994.

[2] SABATINI, A.M., GENOVESE, V., GUGLIELMELLI E., MANTUANO A., RATTI, G., DARIO, P.: 'A Low-Cost, Composite Sensor Array Combining Ultrasonic and Infrared Proximity Sensors', submitted to Proc. Int'l Conf. Intelligent Robots and Systems, Pittsburgh, PA, U.S.A., September 1995.

[3] Technical Annex EC TIDE Project OMNI: 'Office Wheelchair with High Manoeuvrability and Navigational Intelligence for People with Severe Handicap', 1993.

[4] HOYER, H., and HOELPER, R.: 'Intelligent Omnidirectional Wheelchair with a Flexible Configurable Functionality', RESNA '94 Annual Conference, 1994, Nashville, U.S.A., June 17-22, pp. 75-82.

ACKNOWLEDGMENTS

This work is partially supported by the EC TIDE OMNI project under contract TP 1097.

Dr. Angelo M. Sabatini
Scuola Superiore Sant' Anna
Via Carducci, 40
56127 Pisa, ITALY
Tel.: +39-50-883207
Fax.: +39-50-883215
E-mail: SABATINI@SSSUP1.SSSUP.IT

A SIMULATED ENVIRONMENT OF A MULTIMODAL USER INTERFACE FOR A ROBOT

Matthew T. Beitler, Richard A. Foulds, Zunaid Kazi, Daniel Chester, Shoupu Chen & Marcos Salganicoff
Applied Science and Engineering Laboratories
Alfred I. duPont Institute/University of Delaware
Wilmington, Delaware USA

Abstract

The Multimodal User Control project at the Applied Science and Engineering Laboratories (ASEL) is developing a strategy that allows for user control of a rehabilitation robot through the use of multiple modes of interface. The strategy combines pointing to indicate locations and verbal commands to identify objects and actions. The intent of the multimodal control system is to meet the needs of individuals with motor disabilities by allowing them considerable freedom and flexibility to operate a robot in an unstructured environment [1].

To study the intricacies of the interactions between the user and the envisioned multimodal control system a simulated environment is being developed. The simulated environment will be used by consumer researchers to help determine the best way to enable a user to direct commands, control execution of tasks, and communicate environmental parameters which the robotic system is unable to ascertain.

Background

To date, interface strategies for rehabilitation robotics have not met the desires of the disabled community [2]. Command-based interfaces, in which the robot is programmed with predefined movements, expect the items that the robot is manipulating to be in predetermined locations [3][4]. This limits the system to a set workstation type environment. While control-based methods allow the user control of all movements and offer more flexibility than command-based system, they are often slow and very demanding of the user [5][6]. Alone neither of these interface strategies allow the user to effectively operate a robot in an unstructured environment.

The multimodal interface strategy focuses on the integration of command-based and control-based methods in combination with voice recognition of commands and gestures to indicated locations of objects and the desired trajectories that the user wants them moved along. This strategy involves a number of technical developments in order to maintain the simplicity of the user interaction. To accomplish this the multimodal control system will include a Zebra-Zero robot, sensing devices, a three-dimensional machine vision system, and a computer [1].

The multimodal user control interface strategy also makes the user a integral part of the robotic system. The multimodal control system uses the user's intelligence and senses to significantly augment its knowledge base, reactive planning and artificial sensing devices. This scheme allows the user to define the size, shape, color, location, name, etc. of an object, thus relaxing the object recognition requirements of the system.

Statement of the Problem

The development of the multimodal user control strategy depends heavily on the user's spatial perception and interactions. The user's perception of the depth, distance, orientation, and configuration of objects are particularly essential to how the multimodal control system will respond to directives from the user. Although the system does not require the user to provide information about the depth, distance, orientation and configuration of objects, understanding the user's perception of these features is important to insure that commands are executed as the user intended. To design a robust multimodal control system we must first take into consideration:

- How the user perceives the location and orientation of objects
- How the user interacts with objects
- The interplay between the user and the simulated multimodal control system
- How to gather an accurate interpretation of the speech and gestural intimations the user makes
- What level of automation allows the user the best control and flexibility
- How to provide effective feedback to the user as to the multimodal control system's interpretation of their intentions

By studying these issues we will be able to more effectively explain and predict the interactions between the user and the multimodal control system.

An additional challenge which needs to be addressed is the issue of user safety. When the user gives the multimodal control system a command they are expecting the system to carry out that task without injuring them and without damaging the objects it is manipulating. Besides conventional safety rules and intelligent safety devices, an additional method of

503

providing feedback to the user about the plans of the system needs to be developed.

Approach

To prototype and evaluate the multimodal interface strategy, a simulated multimodal user control environment is being created using JACK™, an application developed by the Center for Human Modeling and Simulation at the University of Pennsylvania [7]. JACK™, which runs on a Silicon Graphics IRIS Elan computer, graphically displays articulated geometric figures and allows them to be placed and manipulated in a virtual environment. This virtual world (as shown in Figure 1) contains a fully functional model of the Zebra-Zero robot, models of general objects such as books, cubes, pencils, cups, etc., a 3-D tracking device and other inputs sensors, and a kinematic manipulatable human figure. The simulated environment will also have the advantage of a knowledge based reactive planner. The knowledge based planner allows for flexible and reactive planning in an unstructured real-world domain. The planning mechanism allows for both autonomous planning as well as planning through human-machine interaction [8].

Consumer Participation in Research

The simulated environment's combination of the virtual multimodal user control world and the knowledge based reactive planner will allow it to efficiently evaluate the user's perception and interpretations of a multimodal user control interface strategy. To gather this information and to refine the human factors considerations, extensive consumer research with the simulated multimodal control environment will be conducted. Consumer researchers will be asked to work with the simulated multimodal control environment and will be involved in suggesting changes to the simulation system, which can then be easily implemented for reevaluation. The prototyping steps which will be used in the development of the simulated multimodal control system are:

1) Develop a virtual representation of all the components which exist in and affect the actual multimodal control environment
2) Expand the user command and control features of the simulated environment
3) Conduct consumer evaluations of the performance of the simulated multimodal control system.
4) Implement the consumer suggestions and repeat step 3.
5) Define the strategies for multimodal user control of a rehabilitation robot which will be implemented in the actual multimodal control system

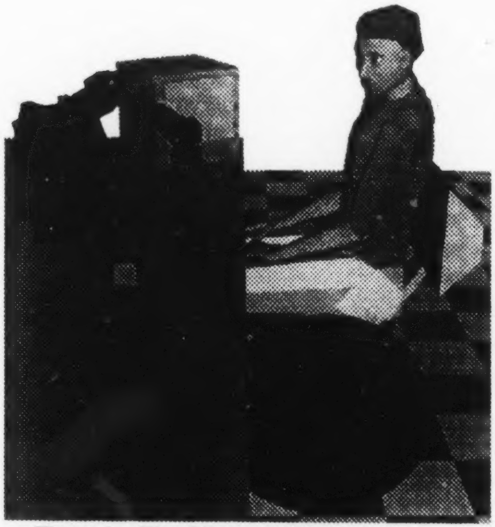


Figure 1: The Simulated Multimodal User Control Environment

The Simulator as a Plan Previewer

To address issues of plan correctness and user safety, the simulated environment will also be incorporated into the multimodal control system during its actual operation as a feedback mechanism. The simulated environment will inform the user of the system's plans and interpretations of the world and can be thought of as a "plan previewer". After the user gives the system an instruction, they will first be able to preview what the system intends to do, via the simulated environment. This is very important because when the user entrusts the multimodal control system with a task, they are "trusting" the system to perform that task correctly. In doing this the user is also taking a "risk" that the system can do the job correctly [9]. The simulation environment is apropos to the trust/risk issue. If the user is going to command the system to perform a task, they need to be confident that the system is going to perform the task adequately. By allowing the user to visually preview of the intention of the multimodal control system, the simulation interface will effectively strengthen the "trust" between the user and the multimodal control system.

The functionality of the simulated environment will gain additional strength as a previewer by taking advantage of the three-dimensional machine vision system. The simulated environment can graphically render parametric object shape models that are extracted by the vision system. This feature allows more of the nuances of the user's real environment to be incorporated into the virtual representation, which allows for more realistic simulations of the multimodal control system's intentions.

Implications

The overall objective of the simulated environment is to improve the design of the interaction strategy for the multimodal control system by rapidly incorporating the consumers' suggestions into the system. The aforementioned method of integrating the creative talents of consumer researchers with the engineering knowledge of the project team will hopefully produce innovative solutions to the problems found when multimodally controlling a rehabilitation robot. An additional goal of the simulated environment is to address the issues of user safety and plan correctness in the multimodal control system by giving the user the option of viewing the actions before the actual multimodal control system performs the actions. This previewing technique should help to reinforce the user's confidence in the system, consequently increasing its effectiveness and usability.

Summary

This research is attempting to set forth a new technique for controlling a rehabilitation robot and to influence the design of robotics technology. Present techniques of controlling a rehabilitation robot have not been adequate, because they failed to consider the needs of the disabled community. The extensive use of consumer researchers gives this project access to knowledge and experiences that cannot be provided by traditional research techniques. It is believed that this consumer insight will help to produce a human-robot interaction strategy which is flexible, efficient and intuitive.

References

[1] Chen S, Kazi Z, Foulds R, & Chester D. (1994). Multi-Modal Direction of a Robot by Individuals with Significant Disability. *ICORR 94 - Proceedings* (pp 55-64).

[2] Batavia A, & Hammer G. (1989). Consumer Criteria for Evaluating Assistive Devices: Implications for Technology Transfer. *RESNA 89 - Proceedings* (pp 194-195).

[3] Seamone W & Schmeisser G. (1986). Evaluation of the APL/JHU robotic arm workstation. *In R. Foulds (Ed.), Interactive Robotic Aids-One Option for Independent Living: An International Perspective* (pp 51). World Rehabilitation Fund.

[4] Gilbert M, & Foulds RA. (1987). Robotics at the Tufts New England Medical Center. *RESNA 87 - Proceedings* (pp 778–780).

[5] Zeelenberg AP. (1986). Domestic Use of a Training Robot-Manipulator by Children with Muscular Dystrophy. *In R. Foulds (Ed.), Interactive Robotic Aids-One Option for Independent Living: An International Perspective* (pp. 29–33). World Rehabilitation Fund.

[6] Kwee H, Thonninsen M, Cremers G, Duimel J, & Westgeest R. (1992). Configuring the Manus System. *RESNA 92 - Proceedings* (pp 584–587).

[7] Badler NI, Metaxas D, Webber B, & Steedman M. (1994). The Center for Human Modeling and Simulation. *<URL:ftp://ftp.cis.upenn.edu/pub/graphics/public_htmp/badler/pap/pap.ps.gz>*.

[8] Kazi Z. (1995). Integrating Human-Computer Interaction with Reactive Planning for a Telerobotic System. *Ph.D. Proposal*, University of Delaware, Newark, DE 19711.

[9] Foner LN. (1993). What's An Agent Anyway? A Sociological Case Study. *E15-305*, MIT Media Laboratory, 20 Ames Street, Cambridge, MA 02139.

JACK™ is a registered trademark of the University of Pennsylvania.

Silicon Graphics and IRIS are registered trademarks of Silicon Graphics, Inc.

Acknowledgments

This research is supported by the Rehabilitation Services Administration (Grant Number H129E20006) and the Rehabilitation Engineering Research Center on Rehabilitation Robotics (Grant Number H133E30013) of the National Institute on Disability and Rehabilitation Research (NIDRR). Additional support has been provided by the Nemours Research Programs.

Matthew T. Beitler
Rehabilitation Robotics Group
Applied Science and Engineering Lab
A.I. duPont Institute
1600 Rockland Rd.
Wilmington, DE 19899

email: beitler@asel.udel.edu
WWW: http://www.asel.udel.edu/~beitler

THE HELPING HAND ELECTRO-MECHANICAL ARM

Saleem J. Sheredos, BEE, MHCA, Barry Taylor, MS, OTR, Rehab R&D
Christopher B. Cobb, President, CEO, Edward E. Dann, Chief Operating Officer
Kinetic Rehabilitation Instruments, Inc., Hanover, MA,

ABSTRACT

Robots can serve as interactive aids for performing personal and vocational activities and improve the quality of life for persons with severe mobility impairments. A major challenge has been making this technology functional, practical, and affordable. The VA Rehab R&D, Technology Transfer Section is facilitating the transfer of the Helping Hand (HH) to commercial availability. The technology transfer process encompasses human factor and clinical trials to validate the developer's claims, safety, reliability, compatibility, effectiveness and commercial readiness.

BACKGROUND

Robotics technology appears to be in a developmental stage similar to that of business computers in the early 1960's (1). Industrial robots are constantly gaining advanced language and mobility. Implementation of the ADA has provided impetus regarding employment and electronic accessibility for users with disabilities. Additionally, Spinal Cord Injury (SCI) research has shown that increased client involvement in purposeful activity enhances personal health and increases longevity (2; 3).

Recent advances in rehabilitation telemanipulators have enabled people with high level quadriplegia to access their environment and function at performance levels rivaling those of persons without disabilities. These state-of-the-art systems can enhance the quality of life of these and other individuals with severe mobility impairments by providing avenues through which personal, educational and vocational goals can be achieved.

Rehabilitation robotics can be divided into two main categories: workstation (fixed-location) and mobile systems. Kinetic Rehabilitation Instruments, Inc. (KRI), Hanover, MA has developed and is manufacturing a precommercial model of the (HH), a w/c mounted electro-mechanical arm. This system permits persons with severe physical disabilities to operate the telemanipulator in tandem with their w/c to establish a measure of independence by manipulating daily-use objects and controlling technologies in the home, community and vocational environments. The arm is designed for simplicity of operation; after as little as five minutes, users have been able to retrieve an object and utilize it as desired (e.g., retrieve a container of water and take a drink).

The HH is modular in design, can be mounted on either side of most powered chairs, and utilizes it's own controller. The unit is streamlined to permit w/c access through standard doorways. The slimness of the arm minimizes obstruction of the user's visual field during operation. There is close matching between the HH ROM and the effective work area. At full reach (48 in.), the HH can lift 4 pounds and, as the arm is retracted, the lifting capacity becomes proportionally greater. The five degrees of freedom of the arm (six, if one includes the user repositioning the w/c to enable the arm to access an object) are facilitated by four 24V motors. Wheelchair installation is performed using a mounting kit which secures the unit to the chair frame directly behind the front caster.

Using the HH control panel, the operator initiates the action of retrieving an object by guiding the arm one degree of freedom at a time until it is in the correct position; he then activates the gripper to grasp the object and directs the arm to the desired end point, whether it be to place a book in view or bring a piece of fruit to his mouth.

A number of important safety features have been incorporated into the HH design including a remote emergency stop switch for the trainer which can override the user control device and reverse the direction of arm movement, a limit on the grasp strength of the gripper, and slip clutches at each motor to protect the user from injury by automatically slipping when a certain amount of pressure (5 lbs/sq. in.) is exerted on the arm. The trainer can also stop the HH manually at any time, if he/she observes the arm making an unsafe movement.

Limited clinical testing by the developer on several prototypic versions of the HH system has successfully demonstrated its potential effectiveness as an assistive technology interface for intended users. Having undergone several design iterations, KRI has now deemed the HH ready for evaluation outside the development environment. The Rehab R&D Technology Transfer program focuses on VA funded R&D outcomes, however, other sources will be considered if the outcomes will fill a need in the rehabilitation of veterans otherwise not being aequately met.

RESEARCH QUESTIONS

The primary goals of the human factor evaluation are to verify the utility, operational and performance features, required maintenance and, above all, safety of the system. The study will also identify changes, modifications and/or accessories, if any, that are needed to improve the HH for optimal use by the intended individuals. In addition, the study will assess training requirements, level and degree of technical support required and readiness for a multi-center pilot evaluation.

METHOD

The HH was installed on a Quickie P-300 w/c belonging to an SCI Service staff person with quadriplegia. The trainer became familiar with the operation of the HH prior to initiating the subject evaluation. The subject utilizes the HH four hours each day in the medical center environment, including the SCI Independent Living Apartment. All subject training and evaluation of the HH is performed under the direct supervision of the trainer. During the execution of tasks, no cues are given unless requested. Using the Task Evaluation Log, the arm's performance is recorded for each task. Any problems encountered are recorded and whether the limitation is attributed to the arm or the user. Also, noted is how the problem was resolved (did the user solve the problem or did the therapist or technical staff intervene).

RESULTS

Installation of the HH was easily accomplished; it took approximately one hour to install the entire system, but the arm could be engaged/disengaged from the w/c mounted "shoulder" motor in two minutes or less. The arm was very easy to learn to use and operate, approximately four hours of training were required for the subject to achieve a high level of operating proficiency. To date, the HH has performed tasks safely, reliably and in a reasonable period of time. The user has been able to perform many tasks with the arm including retrieving objects from the floor, opening/closing a room door and a refrigerator door, turning on a water faucet, retrieving a washcloth, wetting it, turning the faucet off and bringing the washcloth to his forehead, fetching a tissue and bringing it to his nose, operating a wall light switch, retrieving a book, inserting a floppy disk into a computer, picking up a phone, inserting a videotape in a VCR and operating the unit, picking up a cup, filling it with water and heating the water in a microwave, removing the cup and making tea, picking up a spoon and bringing it to his mouth; turning on a stove, picking up food from a table, an putting bread in a pop-up toaster and taosting it. The trainer has been able to stop the arm using the emergency stop switch or manually at any time with no harm to the HH. The arm has not impeded w/c accessibility nor has the assymetric weight of the unit (22 lbs.) on the right front of the frame affected w/c performance. The HH's size and appearance are excellent, and it folds conviently out of the way beside the armrest when not in use. The noise level is acceptable. The power requirements on the chair batteries are minimal.

DISCUSSION

As soon as the human factor testing is successfully completed, a six month pilot evaluation of the HH will be coordinated at four VA medical centers (targeted to commence in 2/95). The pilot will determine the utility, performance and overall value in providing independent living assistance and vocational support necessary to enhance job opportunities and maintain productive employment for persons with severe physical disabilities. The goal is to move this product toward commercial availability and widespread consumer use.

ACKNOWLEDGEMENTS

This technology transfer is sponsored by the Department of Veterans Affairs, Rehabilitation Research and Development Service, under the leadership of John W. Goldschmidt, MD, Director.

REFERENCES

Awad, R.E., et al. (1985). Dissemination issues for medical robots. *Proceedings of the 8th Annual Conference on Rehabilitation Engineering*. Memphis.

Heck, Stephen A., (1988). The Effect of Purposeful Activity on Pain Tolerance. *American Journal of Occupational Therapy, 24*, 577-581.

McCormack, Guy L., (1988). Pain Management by Occupational Therapists. *American Journal of Occupational Therapy, 24*, 582-590.

Saleem J. Sheredos, BEE, MHCA,
Program Manager, Technology Transfer
VA Rehabilitation R&D Service
103 South Gay St., Balto, MD, 21202
(410) 962-2133

Instrumentation of the HANDY 1 for Oral-Motor Therapy

Robert F. Erlandson[1], David Sant[1], Ket Wiadnyana[1], James Rippy[1], and Patricia Nizio[2]
[1]Enabling Technologies Laboratory, Electrical and Computer Engineering Dept.,
Wayne State University, Detroit, MI. and [2]The Detroit Institute for Children

ABSTRACT

Self feeding is a critical ability for independent living. Anecdotal evidence with the HANDY 1 feeding aid suggests that use of the device facilitated self feeding in several children. The Enabling Technologies Laboratory and the Detroit Institute for Children are collaborating on a study to test the efficacy of the HANDY 1 as a therapeutic tool for oral-motor dysfunctions. The HANDY 1 was not designed for this role. An instrumentation package for the HANDY 1 has been designed to provide the data collection, systems setup, and user friendly I/O necessary for therapeutic use in a clinic setting. The instrumentation package is described and preliminary field test experiences reported.

BACKGROUND

Eating independently is an essential ability for empowerment and independence. Anecdotal evidence supports the contention that a robotic feeding aid, the HANDY 1 [1-3], can improve oral-motor skills sufficiently to allow severely disabled children who were thought unable to become self feeding, to become such.

The Detroit Institute for Children is the clinical site for a study to test the efficacy of the HANDY 1 as a therapeutic tool. It is an outpatient facility specializing in the treatment of children with developmental disabilities. The Institute estimates that 60% to 70% of their 4,000 clients have some degree of oral-motor difficulty [4]. Oral-motor dysfunction is a significant problem area.

Children with developmental disabilities are still in the process of development and have not lost acquired functions. If the child's oral-motor system is provided with "appropriate sensory experiences, the maturing nature of the system allows it to adapt for function." [5, p50] A robotic feeding aid provides consistent, repeatable spoon positioning and placement for the child. It forces the child to correctly use lips, jaws and the tongue to remove food. It can do this hundreds or thousands of times if necessary. The therapist is no longer put in the difficult position of being both the "robot" - forced to provide the "feeding" function, as well as serving the human therapeutic roles of monitoring, correcting and supporting the child.

Three children were selected to participate in the instrumentation field test phase. This phase has three stages; a requirements specification stage, the first prototype evaluation stage, and the final version evaluation stage. The purpose of this phase is to evaluate the instrumentation package. This will be followed by the clinical therapy portion of the study.

The selected children had no history of aspiration, possessed sufficient cognitive abilities to understand directions, had adequate seating / positioning, appropriate switch and switch mounting, and possessed the motivation to eat more independently. These children exhibited cerebral palsy, spastic quadriplegia, with moderate to severe impairments in speech and oral motor skills.

HANDY 1 and Therapy - Problem statement with respect to instrumentation

Hegarty and Topping have described the HANDY 1 system [1]. The system has a compact control computer mounted on board. A user control switch can be positioned in most places necessary for single switch control. There is a specially designed spoon and end-effector attachment that scoops food out of a dish and presents it to the user. A scanning visual display is used to position the spoon during setup and also for food selection during the eating phase.

The HANDY 1 was not designed for delivering therapy and serving 4-5 different children per day, 5 days a week. The system can store only one fixed spoon position. That means the spoon feeding position must be setup for each new child. There is no data collection capability.

The setup procedure for spoon feeding position requires following a light sequence on the visual light display. The lights have a dual use. In the setup mode they indicate motor control for the robotic arm. The therapist or caregiver must hit the control switch at the appropriate light to activate the motor. The next sequence of lights indicate the nature of movement, up, down, right, left. Once a motor and movement are selected, a switch closure activates movement. Once specified, the spoon feeding position for a given individual can be saved.

Instrumentation of the HANDY 1

Rational for design

For research purposes the system should allow the therapist to setup the spoon position for each child once and then recall that position for future therapy sessions. For each child and each therapy session the system should automatically monitor specific items; switch hits, the active scan light when the switch was hit, and activity at the spoon. These events should be recorded along with the time of their occurrence.

The instrumentation of the HANDY 1 robot consists of three distinct parts. These are: 1) a microprocessor based controller, 2) mechanical modifications to the robot, and 3) software for the microprocessor controller and host computer.

Microprocessor Controller

A Motorola 68HC11 microprocessor was selected for the controller. The microprocessor functions include: monitoring the visual scanning selection lights, the user switch, and the spoon; activating proper robot functions when requested by either the host computer or the user switch; controlling the robot's power supply; running diagnostic software; and handling communications between the robot and host computer via RS232 serial interface. The microprocessor controller is housed in a sturdy plastic case located just below the robot.

Mechanical Modifications

In order to monitor the feeding spoon activity the original fixed spoon holder provider by the manufacturer was removed and a new spoon holder was fabricated. This new holder allows for the monitoring of vertical spoon movement. The design consists of two parallel aluminum plates between which two micro switches and a spoon holder tube are mounted. See Figure 1. The switch holder also has a tension adjustment bracket which allows the operator to adjust the sensitivity of downward pressure on the switch. Note in Figure 1. the spoon is fastened to the spoon lever by a wing bolt located at the end of the lever. The electricalconnections to the spoon switch are done through the use of highly flexible test instrument lead wire, similar to that used for lab equipment.

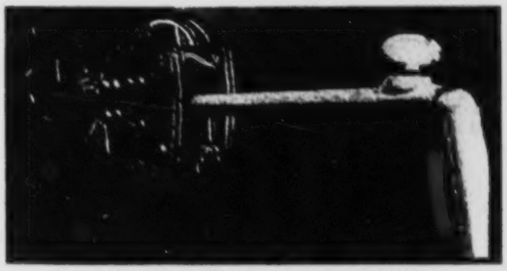


Figure 1. Modified Spoon Holder

Microprocessor Software

Upon activation of the host program a TEST command is used to test the serial port connection. Upon reception of the TEST command the controller will respond with an ACK. At this point the operator has the option to either go to the learn or feed modes. In the learn mode a LEARN command is used to force the robot to enter its setup mode. The operator can now go through the normal setup procedure where each axis is moved from the origin to the desired position. At this time the controller records all axis movement, movement time, and direction. At the end of setup the controller sends the position data to the host computer where it is stored in a data base along with other patient information. At subsequent therapy sessions this information is retrieved from the data base and sent to the controller with the POSITION command. The command takes four previously saved axis arguments that specify direction and movement time. The POSITION command causes the controller to simulate an operator's use of the control switch based on the information in each argument.

During the feed mode when a hit occurs on either the user switch or spoon the controller will issue a "Switch" or "Spoon" data collection string through the communications port At the end of the therapy session a REVERSE command is issued to reset the robot arm to the origin point.

Since the therapist must often attend to the child and be near the HANDY 1 switch and not near the host computer, the control of the SETUP, LEARN and FEED operations can be initiated from both the host computer and the switch on the HANDY 1.

Visual Basic Data Base and User I/O

The Visual Basic programming language was used in the development of the data base and user I/O. This program integrates many different functions, including database management controls, robot mode selection controls, robot diagnostics routines, and file handling routines. The main window is shown in Figure x

The child's name is entered along with an identification number in the specified fields. The therapist can then enter the learn mode by the window selection or switch selection as described earlier. When the child's feeding position is established, that position is saved in the child's data base. At subsequent visits, the system retrieves the saved feeding position and positions the spoon to that spatial location. Hitting the "FEED" icon or user switch (as described earlier) starts the feeding procedure.

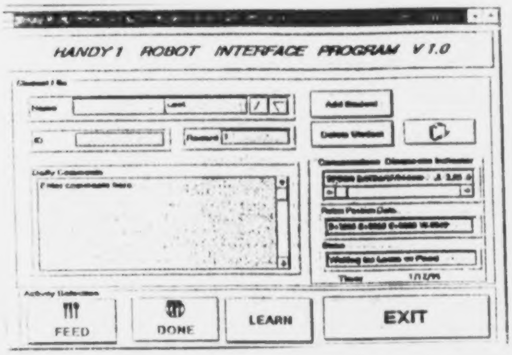


Figure 2. Main Window

The controller collects time intervals between spoon hit, and switch hit data automatically and communicates it to the host computer. The Visual Basic program stores the received data in the child's activity file. The therapist can enter observational notes in the Daily Comments field - these also become part of the child's data base.

Experience to-date

During the requirements specification stage the therapist used the HANDY 1 without any modifications. The therapists and children became familiar with the device and its operating characteristics. Concurrently, a second HANDY 1, at the Enabling Technologies Laboratory, was actually being modified and instrumented. Specific operational features were added to the microprocessor control based on therapist experiences.

When the ETL HANDY 1 was instrumented it was delivered to the Detroit Institute for Children for the prototype testing stage. The intent of this stage was to evaluate the instrumentation package, not full fledged protocol testing. Based on the experience gained during this period several modifications have been made to the microprocessor controller, mechanical attachments and Visual Basic software.

From a clinical point-of-view therapists did notice the following. As expected for this phase, children did not change from a higher to lower percentage of difficulties on the Oral-Motor/Feeding Rating Scale. However, changes were documented on improvements of individual components of a feeding activity, for example, "lip/cheek movement during spoon feeding". All three children demonstrated increased active control of the lips to assist in the removal of food from a spoon. Over time, the children were also noted to execute fewer accidental, non-intended activations of their control switch. This indicates improved skill in use of the HANDY 1 system.

The results of the initial instrumentation field test are promising. It is much to early to draw any conclusions regarding the therapeutic value of the HANDY 1. The initial user reactions and early observations are consistent with those reported by the Keele group [1-3]. The final version of the instrumentation will be tested and debugged. Then the clinical therapy portion of the study will begin.

References

1. Hegarty, J.R., Topping, M.J., " 'HANDY 1' - A Low-Cost Aid to Eating," Proceedings of the 1991 International Conference on Rehabilitation Robotics, Prepared by the Georgia Institute of Technology Center for Rehabilitation Technology and Bioengineering Research Center, Atlanta, Georgia, June 19-20, 1991, pp 17-25.

2. Whittaker, M., "Use of the HANDY 1 Robotic Aid to Eating by 20 People With Severe Disabilities," Proceedings of the 1991 International Conference on Rehabilitation Robotics, Prepared by the Georgia Institute of Technology Center for Rehabilitation Technology and Bioengineering Research Center, Atlanta, Georgia, June 19-20, 1991, pp 109-123.

3. Topping, M.J., "Some Early Experience Gained in the Placement of HANDY 1 Robotic Aids to Eating," Proceedings of the 1992 International Conference on Rehabilitation Robotics, Sept. 15-16, 1992, Keele University, Staffordshire, England.

4. The 1989 Detroit Institute for Children: Facts and Figures.

5. Jones-Owen, J.L., "Prespeech Assessment and Treatment Strategies," in Neurodevelopmental Strategies for Managing Communication Disorders in Children with Severe Motor Dysfunction, Langley, M.B., Lombardino,L.J. (eds.), pp. 49-80.

Acknowledgments:

This is supported by a grant from the Ronald McDonald Children's Charities of Southeastern Michigan

Contact:
Robert F. Erlandson
Enabling Technologies Laboratory
Electrical and Computer Engineering Department
Wayne State University
Detroit, MI 48202
(313) 577-3900
rerlands@ece.eng.wayne.edu

BEST COPY AVAILABLE

DEVELOPMENT OF AN EVALUATION PROCEDURE FOR WHEELCHAIR-MOUNTED MANIPULATOR ARMS

Johanne L. Mattie, Richard E. Hannah
Queen Alexandra Centre for Children's Health
Victoria, B.C. Canada

ABSTRACT

An evaluation protocol has been developed to assess wheelchair mounted manipulator arms. Assessment includes subjective measures such as user surveys and trials, as well as objective and quantitative measures calculated from an engineering analysis. This procedure is being used to evaluate the InventAid Arm, the QA Manipulator, and the Assistive Research and Technology (ART) Arm. Details of the assessment procedure are outlined and preliminary findings of the evaluations are reported.

BACKGROUND

In 1991 it was recognized that a manipulative device could improve the quality of the lives of resident teen-aged boys with muscular dystrophy. These boys are all electric wheelchair users with varying levels of hand and arm function. The research department became involved in rehabilitation robotics, with a goal of making a low-cost manipulator arm available to these boys.

In 1993 a 7 degree of freedom pneumatic manipulator (the InventAid Arm (1)) was purchased from the Papworth Group in England. A year was spent evaluating this arm, resulting in recommended design modifications. Design work of our own was initiated resulting in a 6 degree of freedom electro-pneumatic manipulator - the QA Manipulator(2). In December 1994, an 8 degree of freedom electric manipulator (the Art Arm(3)) was sent to the robotics lab for evaluation. Finding ourselves with 3 manipulator arms, it became evident that a standard evaluation protocol was required.

The field of rehabilitation robotics is developing rapidly, and there are numerous arms currently being evaluated or in a state ready for evaluation. To date, evaluations have typically consisted of experiences from user trials and some subjective comments relating to design weaknesses and strengths. Since many devices are rated by different people at different organizations, comparing devices in a meaningful and consistent way remains a problem.

APPROACH

This work attempts to define a standard assessment protocol. The procedure includes subjective measures such as user surveys and clinical trials, as well as more objective measures calculated from an engineering analysis.

To date, the following protocol has been developed:

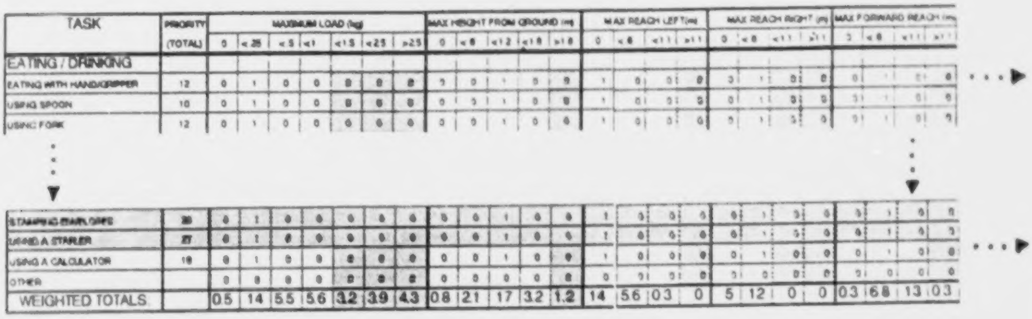
1. User surveys
A one page questionnaire is used to elicit user impressions concerning aesthetics, noise, speed and other variables. Variables are rated on a scale of 1 to 10.

2. Mechanical Assessment
A mechanical assessment of the arm is conducted to evaluate criteria such as maximum load, range of motion, and power requirements.

3. Engineering Analysis of Tasks
"Evaluation matrices" are constructed to evaluate the ability of the arm to perform various tasks (see Figure 1). A list of tasks, based on previous surveys (4,5), is given priority ratings by users. Tasks are then broken down into components required for execution (eg. types of movement required, maximum weight to be lifted). Tasks and their priority ratings are listed as rows in the matrix; components required to execute the tasks as columns. Weighted totals are obtained by multiplying the task priorities for each row of the matrix, then summing each column. Matrices are analyzed to quantify frequency of usage and user priorities for each component. The result is a quantitative assessment of the ability of the arm to perform the given tasks.

4. Clinical Trials
Clinical trials are conducted both in laboratory and "real life" settings, based on user priorities. Trials are based on tasks used in the evaluation matrices,

EVALUATION PROCEDURE



TASK	PRIORITY (TOTAL)	MAXIMUM LOAD (kg)							MAX HEIGHT FROM GROUND (m)					MAX REACH LEFT (m)				MAX REACH RIGHT (m)				MAX FORWARD REACH (m)			
		0	< 25	< 5	<1	<1 5	<2 5	>2 5	0	< 6	<1 2	<1 8	>1 8	0	< 6	<1 1	>1 1	0	< 6	<1 1	>1 1	0	< 6	<1 1	>1 1
EATING / DRINKING																									
EATING WITH HAND/GRIPPER	12	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
USING SPOON	10	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
USING FORK	12	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
⋮																									
STAMPING ENVELOPES	30	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
USING A STAPLER	27	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
USING A CALCULATOR	19	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
OTHER		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WEIGHTED TOTALS		05	14	55	56	32	39	43	08	21	17	32	1.2	14	56	03	0	5	12	0	0	03	68	13	03

Figure 1. Sample sections of evaluation matrix used to quantify frequency of usage and user priority for task components.

selected from categories of eating/drinking, food preparation, domestic tasks, grooming/toileting, leisure/recreation, and desk/school work. Details of each trial are recorded and some sessions are video taped.

5. Recommendations for Design Modification
Short-comings of the arm are defined as a basis for design modifications and improvements to the arm.

A procedure for rating the "efficiency" of different manipulators is currently being defined. Although an arm may be capable of performing a task, it is necessary to be able to compare how quickly and efficiently the task can be done. A protocol is being developed which will involve able-bodied users repeating pre-set tasks.

RESULTS

1. Evaluation of the InventAid Arm
Results of the evaluation showed that the InventAid Arm can be of assistance to youth with muscular dystrophy, however improvements to the aesthetics, noise, and control are necessary before the Arm becomes acceptable to the group surveyed. Results from the evaluation matrix showed that reach and maximum load specifications were adequate for the majority of task however an alternative gripper would be required.

2. Evaluation of the QA Manipulator
The QA Manipulator is currently under evaluation. Initial impressions from users seem to indicate that although the Arm is easier to control and manipulate, further aesthetic improvements are required. A quiet source for pressurized air is still required. Preliminary results from the evaluation matrix show that load and reach specifications are adequate for the majority of tasks and that increasing the gripper opening has improved the Arm's performance ability. Additional gripper modifications and/or attachments could further improve the Arm's capabilities.

3. Evaluation of the ART Arm
The ART Arm is the latest arrival to the robotics laboratory and will be evaluated using the same protocol as the InventAid and QA Arms.

DISCUSSION

Using the above protocol, wheelchair mounted manipulator arms can be assessed to clearly define weaknesses and strengths. Evaluations of different arms can be conducted at different institutes while still maintaining meaningful results.

FUTURE WORK

Future work includes refining the evaluation procedure and developing a protocol to assess the "efficiency" of manipulators. The evaluations of the QA and Art Arms will be completed. We welcome receiving other arms for evaluation.

REFERENCES

1. J. Hennequin, R. Platts, Y. Hennequin, "InventAid, Putting Technology to Work for the Disadvantaged," Arm", Rehabilitation Robotics Newsletter, vol.4, no.2, pp. 1-2, Spring, 1992.

2. R. Burrows, J. Orum, R. Falk, "Pneumatics Manipulator Arm Project Report, Queen Alexandra Centre for Children's Health, March 1994. 1995.

3. A. Moynahan and C. Stanger, "Evaluation of the ART Arm," ASEL Tech. Rep. #ROB9401, Jan., 1994.

4. S. Prior, "An electric wheelchair mounted robotic arm - A survey of potential users," J. Med. Eng. & Technol., vol.14, no.4, pp.143-154, July/Aug. 1990.

5. J. McKechnie, "Results from the 1991 and 1993 robotic aid/manipulator arm surveys," Queen Alexandra Centre for Children's Health, Tech. Rep., Dec. 1993.

ACKNOWLEDGEMENTS

The Vancouver Foundation and the Mr. and Mrs. P.A. Woodwards' Foundation are thanked for their financial support of this work.

Johanne L. Mattie
Fisher Rehabilitation Engineering Building
Queen Alexandra Centre for Children's Health
2400 Arbutus Rd.,
Victoria, B.C.
Canada V8N 1V7
TEL: (604) 721-6732; FAX: (604) 721-6815
EMAIL: cjenkins@orca.gov.bc.ca

THE CONSUMER INNOVATION LABORATORY:
AN EXERCISE IN CONSUMER EMPOWERMENT

James W. Fee, Jr., L. Jane Fee, and Robert S. Piech
Applied Science and Engineering Laboratories,
University of Delaware/A. I. duPont Institute
Wilmington, DE. 19899

ABSTRACT

A prevailing sentiment within the National Institute on Disability & Rehabilitation Research is that any research must incorporate consumer input in order to be truly responsive to consumers' needs for rehabilitation technology. The Applied Science & Engineering Laboratories of the University of Delaware and the Alfred I. duPont Institute (ASEL) have developed a cutting edge project to meet this objective. (For purposes of clarity, the term "consumer(s)" as used here refers to people with various physical or sensory disabilities.) The project, called the Consumer Innovation Laboratory employs consumers as part of an engineering design team to analyse and develop appropriate technologies. The project's organizational structure is described and work with three devices under development is highlighted.

BACKGROUND

In 1993, the University of Delaware's Center for Applied Science and Engineering, located at the Alfred I. duPont Institute, received funding from the U.S. Department of Education's National Institute on Disability and Rehabilitation Research for several assisted technology projects. One of these projects is the Consumer Innovation Laboratory. This project is a consumer-led and consumer-driven research effort. The project explores new methods of integrating consumer knowledge and expertise into a "total design process," and is a forum for ideas and expertise for other projects within the Robotics Rehabilitation Engineering Research Center (RERC) of ASEL.

Consumers have been engaged to work as peers with staff engineers in the development of rehabilitation technology solutions to everyday needs. In their team roles with the engineers, the consumers share in the responsibility for taking project ideas from their inception, through the development of working models, to their submission to manufacturers for commerciailization. This involvement throughout the development process results in three important goals. First, consumers are exposed to the "real world" of product development. They learn quickly that products are not created "overnight", but rather take many hours of involved, concentrated effort. Second, consumer involvement ensures that design and function relate to the real needs of real people. Finally, professional staff are provided with first hand exposure to the subtle individual differences associated with each person's disability. This helps them to have a greater intuitive sense in developing rehabilitation engineering solutions which may address a broad spectrum of individual limitations.

PROBLEM STATEMENT

The project seeks to address the issue of (disabled) consumer involvement in the process of designing assistive devices.

APPROACH

The methodology for this project consists of identifying members of the community who have a disability and also have an interest in the design of one or more assistive devices. The staff at ASEL holds general assembly meetings every two to four months where the project is introduced to newly identified consumers. Those consumers who have a definite interest in a specific device are invited to join a Design Team.

The following is a brief outline of the overall operation and activities of the Consumer Innovation Laboratory.

Outreach: The staff has put extensive effort into making the public aware of this consumer-focused project with the intent of encouraging consumer participation. Formal presentations have been made to the board of directors of the Delaware/Maryland Paralyzed Veterans Association and residents of a local residential care facility for adults with physical disabilities. Announcements, news articles, and general information about Consumer Innovation Laboratory activities have been disseminated through many networking channels within the regional disability community. Examples include:

- Published articles which appeared in the HANDi Network News (a local newspaper for the individuals with disabilities);
- Announcements about meetings with consumers have been distributed to the mailing lists of the Parent Information Center of Delaware, Inc. and A. I. duPont Institute's Public Relations Office;
- Project activity updates mailed out to United Cerebral Palsy of Delaware, Inc., Division of Vocational

Rehabilitation offices and a list of 90 individual consumers and organizations;

- Word of mouth communications spread by project consumer participants to dozens of other consumers;

This cumulative outreach totals approximately 3000 people.

Consumer Participation: There are two basic levels at which consumers are encouraged to participate.

- General Assembly Level- At this level, consumers act as uncompensated advisors for the various design teams. Participants attend meetings held every 2 to 4 months.
- Design Team Level- At this level consumers are compensated at a professional hourly rate. Consumers are expected to meet on a weekly or biweekly basis and participate on whatever level their ability permits in the design of a specific device.

Meetings Held: The Consumer Innovation Laboratory has organized two kinds of meetings which facilitate consumer participation. The first is a general meeting. Open to anyone, it focuses on the generic purpose of the Laboratory with the intent of encouraging expanded consumer participation. The name General Assembly Meeting has been adopted to refer to these general meetings. The second kind of meeting is a smaller gathering that combines consumers and project staff who have agreed to work together on a specific research issue identified by one or more consumers. These smaller gatherings have become known as Design Teams.

General Assembly Meetings: There have been 11 General Assembly Meetings held since the Laboratory was established. These meetings are typically held on a weekday evening for two hours once every two months. Attendance has ranged from as few as half a dozen consumers to as many as 29. The format for these meetings is to have a welcome and introduction period followed by an overview presentation about the Laboratory. Consumers are made aware of the various levels of participation they can have as members of the project. A brief progress report is presented by a member of each Design Team. The General Assembly is then presented with requests for input concerning any questions or problems the Design Team(s) may be facing. Typical questions might be about the kind of interface device to use or the configuration of an activating lever. A list of research problems generated by consumers for possible consideration by the project is reviewed. Presently, the list consists of some 25 items ranging in complexity from a wheelchair backpack to an automatic vacuum cleaner. An opportunity is extended for anyone to add items to this list. The meetings are concluded with an invitation for consumers to consider ongoing participation followed by a general question/comment period and a review of the scheduling for the next General Assembly meeting.

Design Teams: The Consumer Innovation Laboratory has been successful in establishing three Design Teams with consumer participation. Each of these teams is addressing an issue identified by consumers in some previous meeting of the General Assembly. Typically members of the general assembly have expressed an interest in a give item. When four or more consumers have expressed an interest in the same item a Design Team is formed. The three design issues or research problems being actively pursued at this time are:

- an egg breaking device that will enable a person with little or no hand function to separate the contents from the shell independently,
- a wheelchair mounted door opening device to use with any non-automated door,
- a floor cleaning/vacuuming device which can be maneuvered without physical contact so as to minimize the effort required by someone with a mobility impairment (i.e., automatic vacuum cleaner).

The design teams for each of these devices were established several months apart in the order they appear above. The egg breaking team meets weekly while the other two teams meet twice a month. With the exception of the door opener team, the teams routinely meet and work in the Robotics Rehabilitation Engineering Research Center (RERC) facilities at the A. I. duPont Institute. Meeting at the RERC promotes greater information and idea exchange between the consumer researchers, engineering staff, and any others who might want to participate.

Design Team Progress: Three Design Teams are now in place and the following is a brief outline of their progress to date.

Egg Breaking Device: At the outset, performance qualities were listed in order of priority by each member of the group. A final tally of criteria was agreed upon. Areas of concern such as overall performance, safety, maintenance, operation, cost, aesthetics, and installation were included in the "design specification". After this process was completed, attention turned to the generation of ideas that would meet the specifications.

During the next several meetings, different drawings were created by several members of the team and these were discussed. One concern is whether a model can be developed which meets all design criteria and can still be readily mass produced by a manufacturer. While no prototype has been constructed, several promising ideas are being considered.

Door Opener Device: Team progress toward this device has included a needs specification list. This has included device properties deemed essential and ones not critical but preferred. By considering both essential and nonessential but preferred criteria, the group believes it has clearly defined the device and is ready for the next development stage.

The team engineers have constructed manual prototype models of a device and it is being critiqued by the group. The need for flexibility and retractability are important design considerations. The "hand" of this device is clearly taking shape with three or four "fingers" that will grasp and hold, pull and release on command or in programmed sequence. In considering control of the device, design appears to be moving toward operation through the wheelchair's joystick.

Automatic Vacuum Device: As in the other design teams, the automatic vacuum cleaner group has been defining device specifications in terms of demands and preferences. One of the major questions addressed in determining design specifications was: should the vacuum be fully automated (robotic) or manual with adapted attachments that a wheelchair user might find helpful? To answer this question, two experiments were conducted.

First, the power cord of a canister vacuum was rigged to the ceiling with a pulley system and hung across the back of a wheelchair. This was to keep the power cord out of the way of the moving wheelchair. When rewinding the cord it, sagged and hit the wheelchair user in the side of the head.

In the second experiment, the base of a remote controlled toy car was used with a hand held vacuum positioned on it. The remote had two switches; one for forward/backward and one for right/left. Good dexterity was needed to operate the remote and practice was needed to direct the hand vacuum at the dirt and avoid crashing into the walls. It was decided that if this approach were used, a joystick that combined both of the above switches would be needed. A slower speed would also allow the suction of the vacuum to pick up dirt and control the vacuum's movement.

Another major concern relates to the power source and whether a battery system can be found/designed that has enough power without being too large. Several possibilities are being investigated including marine batteries and a new design not yet available to the public.

Newsletter: A newsletter entitled *THE INNOVATOR*, is under development with February, 1995 as the deadline for publishing the first edition. The expected publication schedule thereafter will be quarterly. The newsletter will feature routine columns reporting on issues involving each of the Design Teams. Additionally, there will be a story in each edition featuring other research projects funded within the Robotics RERC as well as a section devoted to consumer input on rehabilitation engineering.

ACKNOWLEDGMENTS

The authors wish to acknowledge funding for this project provided by the National Institute on Disability & Rehabilitation Research, U. S. Department of Education, Grant #H133E30013 and the Nemours Research Programs, and to thank the staff at ASEL for their contributions in time and effort to this project.

AUTHOR ADDRESS

James W. Fee, Jr. M.S.
Research Engineer
Applied Science and Engineering Laboratories,
University of Delaware
Alfred I. duPont Institute
P. O. Box 269
Wilmington, Delaware 19899
Phone: 302-651-6830
Fax: 302-651-6895
e-mail fee@asel.udel.edu

DEVELOPMENT OF THE Q. A. MANIPULATOR ARM

Robert G. Burrows, Richard E. Hannah
Queen Alexandra Centre for Children's Health
2400 Arbutus Rd., Victoria, B.C. Canada V8N-1V7
TEL. (604) 721-6732; FAX (604) 721-8615

Abstract

The Q.A. manipulator arm is a six degree of freedom, wheelchair mounted, pneumatic manipulator which was developed after realizing that a small, lightweight wheelchair mounted manipulator could improve the level of independence of wheelchair users.

Background

In 1991 research was started to evluate the usefulness of a wheelchair mounted manipulator arm for improving the level of independence of children with muscular dystrophy. As part of this research the Inventaid Arm(1) was purchased and evaluated. The Inventaid Arm is a wheelchair-mounted pneumatic manipulator with six degrees of freedom and gripper.

Statement of Problem

After evaluating the Inventaid Arm it was realized that, although it is of use to wheelchair users, it did not meet the needs of our clientele. Criteria for the development a new arm included:

1. Improved aesthetics
2. "Parked position" out of user way
3. Improved air muscle design to minimize leakage
4. Reduced bulk of arm
5. Improved load carring capability (up to 4lbs.)

Design work for a new arm, the Q.A. manipulator Arm, was initiated with the objective of meeting these criteria.

Rationale

The rationale for pursuing and improving an arm based on the use of pneumatic actuators included their low cost, relative simplicity and ease of maintenance. These were some of the criteria cited by Hennequin in the original development of the InventAid Arm. It was felt that, to be successful in the field of rehabilitation robotics, a manipulative arm would have meet these criteria plus be safe and easy to operate. Pneumatic actuators seem to offer these advantages.

Design

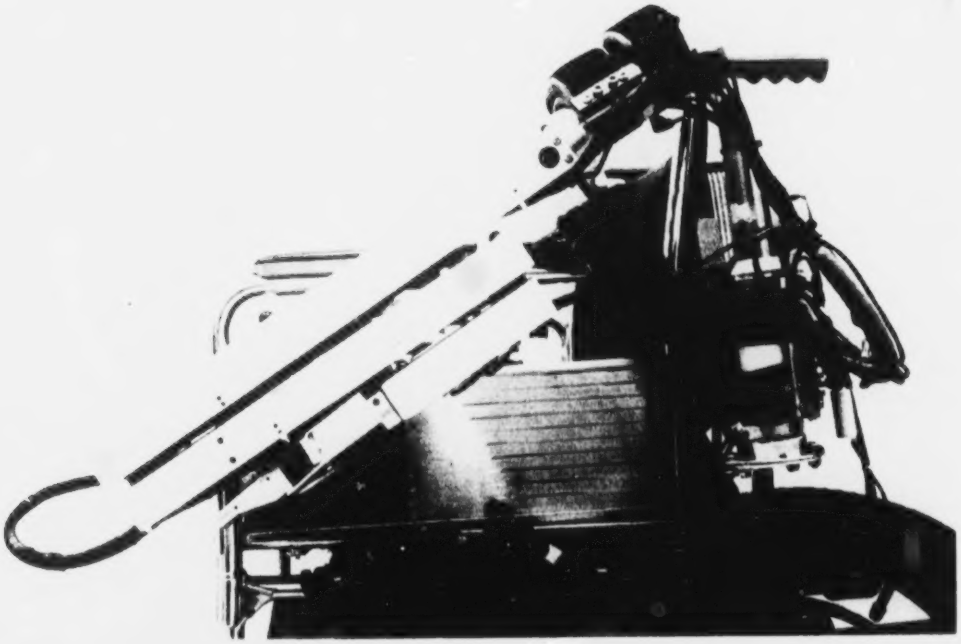
The Q.A. Manipulator Arm uses a combination of Flexator air muscles, pneumatic cylinders, and DC electric motors.

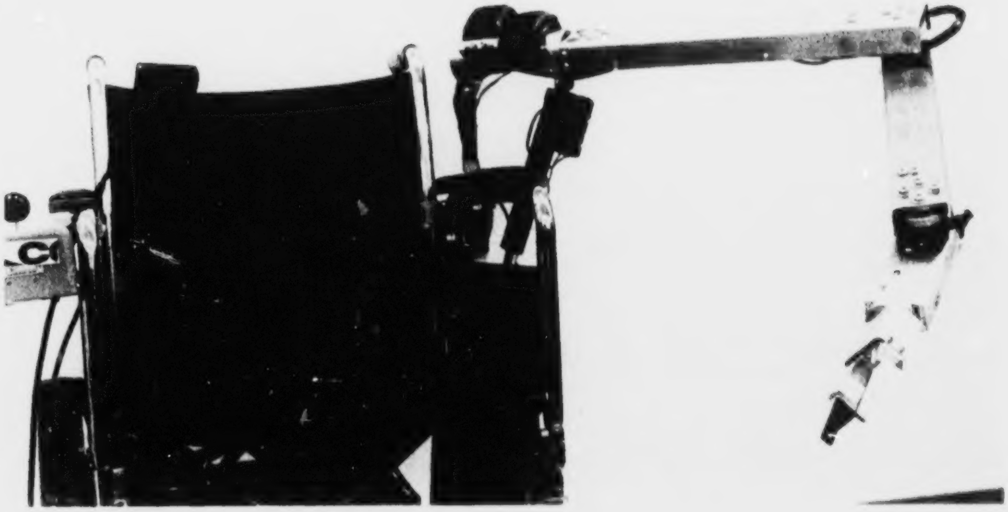
The Flexator air muscle was invented by Mr. Jim Hennequin of Airmuscle Ltd, U.K. The muscle consists of a piece of layflat hosing, folded in half and clamped to a tube. Webbing strap is attached at one end to the tube, run over the hose,through a slot in the tube and wrapped around a shaft which is mounted on bearings in the centre of the tube. As the hose is inflated, the strap is unwound from the shaft. Using two opposing muscles gives rotation in both directions.

On the Q.A. Arm Flexator air muscles are used for shoulder swing and rotation because of their ability to provide high torque and a large degree of rotation within a small space. An electric linear actuator was used for shoulder elevation to eliminate the "bounce" associated with lifting heavy loads with pneumatic actuators.

Elbow and wrist joints are actuated using pneumatic cylinders coupled with positive drive belts and pulleys. This setup provides 180 degrees of rotation, allowing the arm to fold on to itself to facilitate easy storage.

The gripper is a simple, two parallel finger design actuated by a pneumatic cylinder. The gripper is capable of continuous 360 degree rotation by means of a small D.C. motor/gear reducer unit.





THE Q. A. MANIPULATOR ARM

Control System/ User interface

Pneumatic servo valves, located in a central control box, are used to control the actuators. Air is supplied at 100 P.S.I. by a small 24 VDC compressor, rubber mounted to the wheelchair frame.

The manipulator arm is always under direct control of the user. This eliminates any possible malfunction associated with computer control, and reduces the cost.

Two user interfaces are now being used, the simplest being a keypad which can either be held in one hand or mounted to the chair. The use of a joystick is currently being assessed.

Evaluation

The Q.A. Manipulator arm was mounted on a standard Everest & Jennings electric wheelchair. After preliminary testing it was found that control was improved. Although the Arm folded away beside the chair and that the esthetics were improved it is still too noticable to be excepted by our clientele.

The Arm is currently being evaluated using the same procedure as with The Inventaid Arm and The ART Arm.

Future Work

After final evaluations have been completed, improvements based on the recommendations made will begin.

References

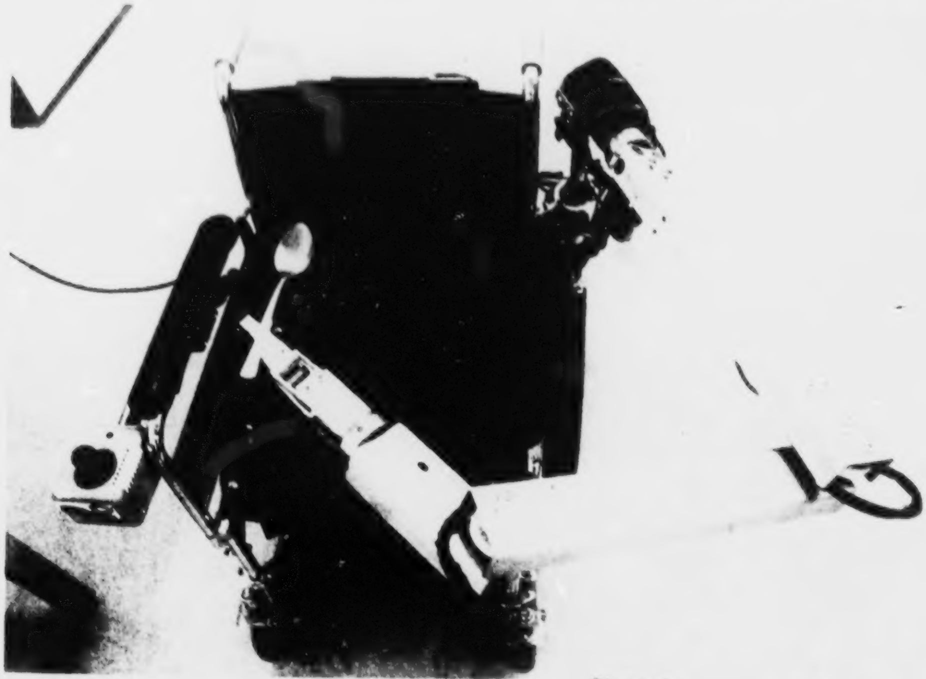
1) J.Hennequin, R. Platts, Y. Hennequin, "Inventaid, Putting Technology to Work for the Disadvantaged" Rehabilitation Robotics Newsletter, vol.4 no.2, pg. 1-2, Spring, 1992

2) J. McKechnie "To Determine the Usefulness and Potential of a Wheelchair Mounted Manipulative Arm for Children with Muscular Dystrophy" Queen Alexandra Centre for Children's Health, Tech. Rep, March 1994

Acknowledgements

This work was funded under grants from the The Vancouver Foundation and The Mr. & Mrs. P.A. Woodward's Foundation

Robert G. Burrows
Fisher Rehabilitation Engineering Building
Queen Alexandra Centre for Children's Health
2400 Arbutus Rd., Victoria, B.C. Canada V8N-1V7
TEL. (604) 721-6732; FAX (604) 721-8615
EMAIL:cjenkins@orca.gov.dc.ca



The V.A.H.M. project (Autonomous Vehicle for Disabled Persons) : First Results

P.Pino*, Y. Agostini*, G. Bourhis*, J.M. André**, B. Brugerolle***, H. De Barmon***
*Labor. d'Autom. et d'Electr. Industrielles, Univ. de Metz, Ile du Saulcy, 57045 Metz Cedex 01, France
**Institut Régional de Réadaptation, 35 rue Lionnois, 54042 Nancy Cedex, France
***Centre de Réadaptation Fonctionnelle 54690 Lay-St-Christophe, France

ABSTRACT

The VAHM project aims to bring a piloting assistance to powered wheelchairs using techniques coming fom mobile robotics. So it is possible to call upon local primitives like "wall following" or "obstacle avoidance", or to plan an automatic trajectory. After a brief explanation of how the system works, in this paper we describe the results of the first trials. They concern four impaired persons in a rehabilitation center.

INTRODUCTION

The usefulness of a powered wheelchair for motor impaired people no longer needs to be demonstrated. However, in spite of the progress in their conception, particularly at engine control level, it still proves difficult or impossible to use for some potential users on account of excessively weak residual physical capacities or a serious spasticity for example [1]. If a simple adaptation of the command sensor is not sufficient to get round these difficulties, we have to consider calling upon a navigation aid which could copy mobile robotics techniques. Various works in this way are described in the literature concerning either the elaboration of navigation help local primitives (automatic obstacle avoidance [2], person following [3], floor line following [4]), or the achievement of planned trajectories in a modelled environment. These models may be made of natural beacons (walls, doors [5]) or artificial ones (visual cues read by cameras [6]). The use of these systems in real conditions is nevertheless rarely evoked.

Within the framework of the VAHM project ("autonomous vehicle for motor impaired people") we aim to realize a modular system which would be able to adapt to a great variety of situations (rehabilitation centre or home, room or corridor, ...) or levels of disability. As a corollary, such a system might be use as an evaluation tool in order to determine the real needs for a "clever" steering assistance.

SYSTEMOVERVIEW

The robot hardware architecture is made up of a portable PC486 connected to a Robuter™ mobile base (Fig.1). Its two driving backwheels associated to two free frontwheels give it mobility characteristics similar to that of a standard electrical wheelchair, in particular the non-holonomic constraint. The association of a belt of 14 ultrasonic sensors with dead reckoning information allows to realize autonomous motions as well as robot location if the environment has previously been modelled [7], [8].

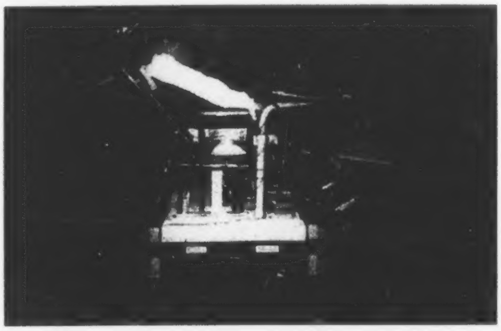


Fig.1: VAHM mobile base

Three main working modes are available :

*In the manual mode robot control is not assisted. So we find the usual working of a powered wheelchair again, with a proportional sensor or a simple switch associated to a scan of the different icons on the screen ("backward", "forward", "left" and "right").

*The assisted-manual mode allows access to local primitives : the choice of a "right wall following" or a "left wall following" engages an automatic movement along the wall taking into account possible shortcomings such as an open door. Likewise, after manual positioning, the "obstacle avoidance" commands the robot to go straight on. If there is an obstacle we skirt round it and then come back to the initial trajectory.

* The automatic mode needs a modelled environment. At present we use a topological model to calculate trajectories represented as a set of points located in free spaces allowing for the wheelchair to pass [9]. The goal definition and the choice of the final orientation may be done on the screen with a geometrical representation of the robot's reachable environment. We may also select the destination semantically ("television", "bathroom"). This last method restricts the number of au-

thorized motions but simplifies the man-machine conversation.

METHOD

In order to validate the basic principles of the VAHM robot and to position our future works, a first set of trials was carried out in a rehabilitation center. Four persons with various levels of disability took part in this evaluation. The robot's movement environment (fig.2) includes physiotherapy rooms, corridors and an apartment intended for the rehabilitation of people with cognitive impairment. We only modelled the apartment (1) and the part of the corridor which goes from it to the swimming pool (3). Let's note that the apartment exit is a difficult chicane trajectory for a wheelchair.

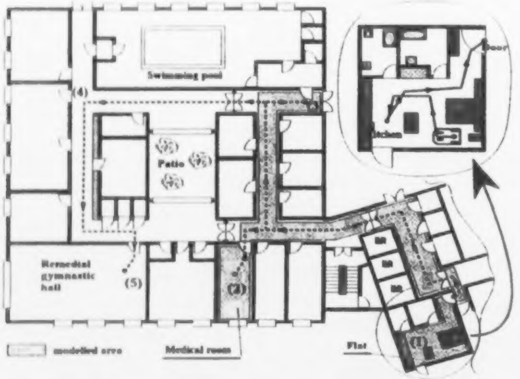


Fig. 2 :Test environment

Each trial began by a training period without robot motion in order to familiarize the user with the different choices which appear on the screeen. During the execution of the autonomous motions only the "STOP" order may be selected . For safety reasons, mode changes are done while the wheelchair is stationary. In fact the robot moves in real conditions with rooms or corridors which are possibly cluttered up with equipment or with people on wheelchairs. For each person the way is imposed. On the other hand, the working mode may be free or imposed according to the section covered. In particular, for the first three persons, the automatic mode is used in the apartment (1) and from the apartment to the room (2). Likewise we impose "wall following" in the corridor (4) and "obstacle avoidance to go out of the apartment for the second time.

RESULTS

The first user easily steered his powered wheelchair with a standard joystick, no adaptation being necesary. The robot command did not cause him any problem other than the usual training phase for a new vehicle. However, on account of his good mastery of electrical wheelchair steering, this robotized system may be useful for him only if the access to the automatic functions is faster than the equivalent manual motion. For instance, in the apartment, trajectory planning has no interest for him, whereas a "door passing" primitive (not yet implemented) might bring some driving comfort if it may be automatically engaged in front of a door or a narrow passage.

The second trial concerns a quadriplegic who controls his wheelchair with slightly adapted joystick using the back of his hand. Without being impossible,fine manoeuvres are difficult for him. Except for some initial confusions, understanding the robot's command proves quite easy. On the other hand piloting assistance appears to have a much more obvious interest than for the previous subject. In some delicate situations such as the apartment exit or entrance, this assistance proves to be almost indispensable. In other cases (cluttered corridors), it brings an appreciated driving confort. The security factor in particular has been positively emphasized in this trial, just like the reduction of the effort due to the number of manoeuvres.

The third subject who takes part in these trials has very reduced physical possibilities : she was only able to switch on a head-stick in order to communicate or to control the environment. So all the choices may be done by icon scanning on the screen followed by a validation. The robot manual control has turned out to be laborious, which was foreseeable, as this completely dependant person does not pilot a powered wheelchair. Among the functionalities we tried, the automatic mode might be the most interesting in the majority of situations. Its use in the apartment has nevertheless been frequently chopped by stoppings asked either by fear of obstacles which are too close, or by an accidental rest on the switch.

The last trial goes beyond the simple mobility help framework : this fourth subject is a young blind person for whom the use of an electrical wheelchair is forbidden not due to his motor but sensory disability. The VAHM robotized system was not initially designed for such a case. So we have adopted a special scenario : this time all the actions are imposed, and are selected with a speech recording unit associated to a switch. The path begins with an automatically planned motion from the room (2) towards the swimming pool (3). A "wall following" takes us as far as the corridor end (4). The "obstacle avoidance" function allows to end the motion to the room (5). All along the way the speech synthetizer expresses the important environment units ("physi-

BEST COPY AVAILABLE

otherapy room", "swimming pool"), as well as abnormal wheelchair motions ("obstacle avoidance on the right"). This time locking situations may appear since the user has got no possibility of choosing the working mode according to the environment he perceives. It seemed obvious here that richer information might be given in order to envisage a more common use.

DISCUSSION

From a technical point of view the trials described above have been successfully achieved. Some progress must however be made on several points. To increase navigation confort and safety, the ultrasonic data treatment has to be improved (sampling frequency increase, erroneous data filtering). Likewise, at present, the localization algorithms need a geometrically modelled environment. This condition was only verified in the apartment. Everywhere else we have only used dead-reckoning data in order to localize the robot approximately. For the movements in the corridors new procedures would be implemented such as a systematic search for the doors, for example. Moreover, implementing some behaviour rules should improve the working of the robot : automatic search for the perpendicular wall at a corridor intersection during "wall following" achievement, automatic set on of a "door passing" primitive, ...

We may also comment on the appropriateness of the VAHM system with the expected application. In particular, these first trials have clearly shown the interest of the robot's modular architecture : the robot's adaptation to the four subjects, whose levels of disability were very different, was fast and easy. Moreover, some working modes proved to be more interesting than others depending on the environment and on the user. Thus the automatic mode seems indispensable in the apartment if the pilot's interface sensor is only a single switch. On an other hand, if the subject uses a joystick quite well, the "obstacle avoidance" primitive proves to be more efficient due to the room crampedness. Likewise the "wall following" function appears more comfortable to use in the corridors than the "obstacle avoidance", the trajectory to execute being defined better. Let's finally note that for the last trial with the blind pilot, we do not draw yet definitive conclusions. Our purpose was only here to question ourselves on an application which is, from a technical viewpoint, quite similar to a navigation help for people with cognitive impairment [10].

CONCLUSION

In this paper we have described the first evaluation results of a mobile robotic application to the motor impaired mobility aid. They have brought to light the advantages of a modular architecture which is able to adapt to the user's physical capacities and to the robot's environment. Future works will try to improve the navigation and localization algorithms and to increase the robot's reasoning capacities. An implementation on a standard wheelchair is also envisaged.

REFERENCES

[1] Commission of the European Communities, Technology Initiative for Disabled and Elderly People, 1993-1994 Workplan, pp.43-44.

[2] D.A.Bell , J.Borenstein, S.P. Levine, Y. Koren, L.Jaros, "An assistive navigation system for wheelchairs based upon mobile robot obstacle avoidance", IEEE Int. Conf.on Robotics and Automation, San Diego, California, 1994, pp.2018-2022.

[3] S.P. Levine, J. Borenstein and al., "Semi-autonomous mobile robot platform for rehabilitation and other applications", 2nd Workshop on Medical and Healthcare Robotics, Newcastle-upon-Tyne, UK, 1989, pp.15-18.

[4] H.Wakaumi, K.Nakamura, T.Matsumura, "Development of an automated wheelchair guided by a magnetic ferrite marker lane", Journal of Rehabilitation Research and Development, vol.29, n°1, 1992, pp.19-26.

[5] R.L. Madarasz, C. Lorren, R.F. Cromp, N.M. Mazur, "The design of an autonomous vehicle for the disabled", IEEE Journal of Robotics and Automation, Vol.RA-2, n°3, 1986, pp.117-126.

[6] J.D.Yoder, E.Baumgartner, S.B.Skaar, "Reference path description for an autonomous powered whellchair", IEEE Int. Conf.on Robotics and Automation, San Diego, California, 1994, pp.2012-2017.

[7] G.Bourhis, K.Moumen and al."Assisted navigation for a powered wheelchair", IEEE Int.. Conf. on SMC., Le Touquet, France, 1993, pp. 553-558.

[8] G.Bourhis, O.Horn, Y.Agostini, "Location and high level planning for a powered wheelchair", IEEE Int.. Conf. on SMC, San Antonio, USA, 1994, pp. 2629-2634.

[9] A. Pruski, "Multivalue Coding : Application to autonomous robots", Robotica, vol 10, 1992, pp. 125-133.

[10] D.L.Jaffe, E.E.Sabelman, G.E.Curtis, "Responsive environment project-Transparent navigation assistant", RESNA, 1992, pp.176-178.

Pierre PINO
L.A.E.I., Université de Metz, Ile du Saulcy
57045 Metz Cedex 01, FRANCE
Tel (33)87-31-54-33
Fax (33)87-31-53-33
Email bourhis@laei.univ-metz.fr

A HOUSEHOLD MOBILE DOCKING ROBOT FOR THE ASSISTANCE TO THE DISABLED

Paolo Dario, Eugenio Guglielmelli, Cecilia Laschi, Claudia Guadagnini
ARTS Lab
Scuola Superiore S. Anna
Pisa, Italy

ABSTRACT

This paper presents the European TIDE-MOVAID project which seeks to offer to all users, but especially the disabled and the elderly users, more comfortable and enjoyable access to non-specialised, consumer products. This goal will be achieved by taking two different (but related) approaches: the majority of users will be catered for by the development of friendly interfaces for kitchen appliances; severely disabled users or bed-ridden users will be catered for by the development of a multi-functional modular robotic assistance unit which will give users access to consumer products via distributed fixed activity workstations. In the following a brief description of the proposed approach and of the basic characteristics of the system are reported. Finally, an overview on the current status of the project and on its future developments is given.

BACKGROUND

Nowadays, robotics could provide innovative tools for the generation of a new, more technological, concept of assistance: there is an opportunity to demonstrate how robotics could not only replace but also support a huge variety of potential users, including the disabled and the elderly, in everyday activities. In fact, the high cost and the limited availability of human caregivers make the solution of using robotic systems, which can allow the users to actively interact with the environment, particularly attractive. Furthermore, alternate strategies to deal with the different aspects of physical disability are still either areas of active research, like the application of FES (Functional Electro-Stimulation), nerve-grafting and nerve-regeneration, or not reliable and efficient enough, like the training of animals such as dogs and monkeys, to produce effective results before a long period of further investigation. On the contrary, robotics technology could represent a viable, surely partial, but near-term solution to enhance personal independence for the disabled [1]. Different configurations have been considered in the past for the development of robotic devices for the assistance to the disabled, such as fixed workstations or wheelchair-mounted manipulators. Also the concept of an autonomous mobile manipulator has been investigated [2] [3]. This solution is particularly attractive since it makes possible to avoid the creation of specialised environments dedicated to the disabled and the elderly. The MOVAID project aims at facing the main technical and functional problems inherent in the development of mobile robots for residential care so to demonstrate its commercial potentialities.

THE MOVAID OBJECTIVE

As it was demonstrated during the URMAD project [3], the amount of resources which have to be incorporated on a completely autonomous mobile system system significantly affects its dimensions, its battery operation, due to high energy consumption, and its total cost. A process of engineering and optimisation of software and hardware resources is required before effective use of this system in the domestic environment could become actually feasible. At present, possible realistic scenarios of use of such systems are limited to hospitals and other institutions where most of the economical and dimensional constraints could be of minor concern. The EC TIDE-MOVAID (MObility and actiVity AssIstance systems for the Disabled) project aims at overcoming these drawbacks: a new system, including a mobile robot and dedicated interfaces for domestic appliances, is being developed by a European consortium. The MOVAID prototype, which is expected to be completed by February 1997, will have high autonomy of operation but still respecting the limitations imposed by a normal household environment so as to avoid heavy adaptation of the house. This goal is being pursued by partially distributing resources in the environment instead of concentrating them on the vehicle; the mobile unit could then be reduced in terms of weight and dimensions.

THE MOVAID APPROACH

From a general point of view, activities of daily living (ADL tasks) are largely of two types: ``chores'', which are physically demanding or tedious (e. g. cleaning, appliance operation, etc.), and more enjoyable activities, such as preparing food in the kitchen at home. In future domestic scenarios, ``chores" could be performed by autonomous or semi-autonomous machines, which would require little interaction with the user. On the other hand, more enjoyable activities require the level of user involvement to be optimised rather than minimised in order not to deny them the feelings of satisfaction and empowerment which active, succesful task performance can engender. By pursuing this approach it will be possible to maximise the user's real and perceived independence; this is of particular concern especially when the users are disabled or elderly people.

As shown in Figure 1, the basic idea of the MOVAID approach is to implement distributed activity workstations in which a mobile unit can ``dock" and operate in the vicinities of the user's bed as well as in the kitchen, where a remote control system enables a bed-ridden user to command the execution of some predefined tasks related to food preparation.

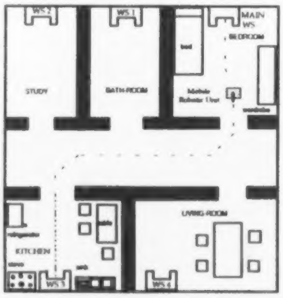


Figure 1. The basic philosophy of the "MOVAID" system.

As long as distribution of resources is well balanced and technologies are properly integrated in the domestic environment, such a realistic solution could represent a good compromise between the current state-of-the-art in advanced robotics and the ideal concept of the autonomous robotic assistant in a modern domestic scenario, thus also favouring a rapid commercial exploitation. One of the key components of the MOVAID workplan is the setting up of a demonstration system designed for a typical home environment. A mockup of the system has been developed to evaluate the performance while executing some typical ADL tasks. The demonstration system will enable realistic user trials to be carried out, in order to evaluate the effectiveness of the system, and to gather information which can be used to revise and improve the sub-systems. The preliminary design of the MOVAID prototype is shown in Figure 3.

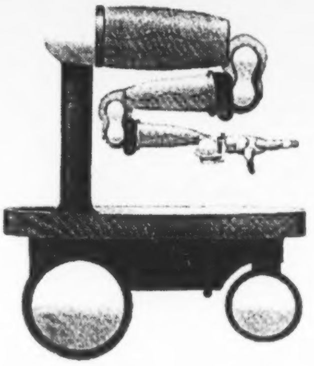


Figure 2. The preliminary design of MOVAID.

THE MOVAID SYSTEM

Referring to Figure 1, two possible *activity workstations* have been identified and a mobile unit is able to operate in the vicinities of the user's bed as well as in the kitchen, where a remote control system enables a bed-ridden user to command the execution of some predefined tasks related to food preparation. Bed-ridden users will be able to operate the robot from a single bedside interface, with tasks in the kitchen being controlled in three possible ways: via radio link, by teleoperation, via the remote controller.

More mobile users will obviously be able to use these interfaces too, or can use interfaces close to the workstations located all around the home environment. As far as practicable, the MOVAID system will be based on the M3S standard.

The main components of the MOVAID system are:

- a mobile unit equipped with: an 8 d.o.f. robot arm with low-level controller and the MARCUS gripper; simple sensory systems for obstacle avoidance, navigation and docking; and a radio link. This unit, will be tested for a variety of different tasks, in the home or in a hospital or other institution.
- two robotic workstations for executing predefined tasks which are related to common, everyday activities: the workstations and their peripherals (e.g. vision system) could be adapted by users who already own a robot arm (whether mobile base-mounted or wheelchair-mounted), and they would have the same functions as the mobile base-mounted robot arm.

- 'friendly' user interfaces to the workstations: these will be enable users to control the technology in a simple, satisfying and effective manner.
- dedicated interfaces for kitchen appliances.

These interfaces will also enhance the effectiveness of the robot, which will benefit from the ease of use provided in the same way as human users. This will allow also to the severely disabled users to execute tasks related to food preparation via the MOVAID system. Thus MOVAID will be driven by the needs of users at every stage, but with close attention being paid to the practical requirements which govern industrial implementation of the results of the research. In principle, MOVAID will seek to bring users the most advanced and innovative technology that current research can offer. In the system definition stage a limited number of domestic appliances under development by Philips and to appear on the market in the next two-five years will be selected. For these appliances novel interfaces based on the MOVAID approach will be designed, implemented and tested with a large number of elderly and disabled users.

DISCUSSION

During the first year of the project (February 1994-February 1995) a careful analysis of the user needs has been carried out leading to the definition of the main user requirements for the whole system. According to the adopted user-oriented approach, this analysis involved a multi-disciplinary team composed by designers, engineers, psychologists, anthropologists, carers, potential end users, rehabilitators and other experts. Based on the results of this work, the design concepts of the first MOVAID prototype have been defined. Some typical tasks related to common domestic daily activities (e.g. cooking, cleaning) have been identified as the demonstrative operations to be performed by the prototype of the system during the final demo planned for February 1997. These operations are basically of two types: unpleasant tasks, such as cleaning the bathroom or removing dirty sheets from the bed, which should be automated as much as possible; and pleasant tasks, such as cooking and eating a meal, which require a deeper level of involvement of the user. Friendly user interfaces for the robotic system and for different small kitchen appliances (e.g. microwave oven, citrus press) have been designed so to make appliances accessible by non-expert able-bodied and moderately (i.e. elderly) disabled users. Dedicated interfaces based on the M3S standard, a specific standard for assistive technology, will give access to severely disabled users too. A mock-up full scale model and a realistic animated graphical simulation of the system have been implemented and presented to a selected group of potential end users (representing the widest range of the possible functional profiles) for preliminary validation. The prototype of the system is currently under development and it is expected to be completed by 1996.

Future work will concern the implementation of an early prototype of the system by February 1995. This prototype will allow to validate with the final end users the design of the system before proceeding to the final implementation of the first complete MOVAID demonstrator which is expected to be available before the end of year 1996. Clinical testing and evaluation with elderly, moderately and severely disabled users will follow in collaboration with the Centro Protesi INAIL (Vigorso di Budrio, Bologna, Italy), the University of Ancona, the Swiss Fondation for Electronic Aids (Neuchatel, Switzerland) and the PROPARA centre of Montpellier (France).

ACKNOWLEDGEMENTS

The TIDE - MOVAID project is funded by the European Union/ DGXIII under contract N. TP1270.

REFERENCES

[1] Van Der Loos, H. F. M., Michalowski, S. J., Hammel, J., Leifer, L. J., Stassen, H. G., (1988). Assessing the impact of robotic devices for the severely physically disabled, Proc. First Int. Workshop on Robotic Applications in Medical and Health Care, Ottawa, Canada, 1, 1-6.

[2] Van Der Loos, H. F. M., Michalowski, S. J., Leifer, L. J., (1986). Design of an omnidirectional mobile robot as a manipulating device for the severely disabled, Proc. of the 9th Annual Conf. on Rehabilitation Engineering (RESNA), Minneapolis, MN.

[3] Dario, P., Guglielmelli, E., Mule', C., Di Natale, M., (1993). URMAD: an autonomous mobile robot system for the assistance to the disabled, Proc. of the Int. Conf. on Advanced Robotics (ICAR '93), Tokyo, Japan, 341-346.

Paolo Dario, Professor of Mechatronics
ARTS Lab - Scuola Superiore S. Anna
Via Carducci 43, 56127 Pisa, Italy
+39-50-883207/560108 (Ph.) / 883215 (Fax)

A MOBILE ROBOTIC UNIT FOR CLINICAL AND RESIDENTIAL CARE

Paolo Dario, Eugenio Guglielmelli, Cosimo Mulè
ARTS Lab
Scuola Superiore S. Anna
Pisa, Italy

ABSTRACT

This paper presents the first Italian mobile robotic unit for the assistance to the severely disabled in partially structured hospital and domestic environments. The system includes a static PC workstation and a mobile unit capable of autonomously navigating avoiding unknown obstacles (e. g. moving persons), and of recognizing and grasping known objects. In the paper, after a brief discussion on the main motivations and the basic philosophy of the URMAD project, the integrated system is presented and a brief description of the main subsystems is included. Most of these subsystems have been purposely developed according to the requirements of the proposed application Finally the preliminary results of the field testing stage are reported and the potential applications of the URMAD system are discussed.

BACKGROUND

In recent years the demand for systems which assist or replace humans during servicing tasks for hospital as well as residential care, has increased to the point where there are numerous major academic and industrial laboratories actively involved in research. Historically, the first configuration which has been investigated is the bench- or table-mounted manipulator included in a completely structured desktop workstation. Even though various systems based on this approach were positively evaluated with users [1] and some commercial products already appeared on the market, such as the DEVAR system (Tolfa Corporation, Palo Alto, CA) and the RAID system (Oxford Intelligent Machines Ltd., Great Britain), yet they seem to be particularly suitable for assisting disabled employees for executing vocational tasks at their workplace. A second possible approach is the use of a wheelchair-mounted manipulator which represents an attempt to allow operation in a variety of different environments. The technical problems inherent in controlling a manipulator mounted on an unstable vehicle are still a subject of ongoing research. However, this solution does not actually addresses all disabled users, but only those with lower limb disabilities. Consequently, it seems to have limited concrete perspectives to become economically attractive by inducing mass market demand. The third solution is that of using a mobile vehicle, possibly equipped with a manipulator and additional sensor systems for autonomous or semi-autonomous operation.. As a sample, the VA Rehabilitation R&D Center (Palo Alto, CA) has already developed [2] a prototype of the Mobile Vocational Assistant (MOVAR) demonstrating the potential usefulness of such a system. Moreover, mobile robots could also become one answer to the current shortage of help in hospitals, as well as one solution to the problem of the diseases (lumbago, low back pain) which affect the personnel involved in heavy physical tasks such as lifting a patient and carrying him/her to the toilet or changing dirty sheets in the bed. An example of a hospital transport mobile robot, the HELPMATE, has been presented recently by Transitions Research Corporation (TRC Inc., Danbury, CT, USA). The robot has been designed and built for addressing the need for assistance with such tasks as point to point delivery [3]. The concept of a mobile robotic assistant is surely the most sophisticated one, but it is also the most generally applicable, since it can result attractive for both able-bodied and disabled users This paper reports the activity carried out by an Italian team during last two years for the development of the URMAD system, an Italian robotic platform devised for service applications.

THE URMAD OBJECTIVE

The URMAD project was conceived to study, implement and demonstrate a prototype robotic system capable of operating semi-autonomously in a partially structured domestic environment. The main goal was to develop a system that would benefit a disabled person by performing tasks that are normally taken for granted by able bodied persons. In order to ensure good acceptability of the device by the potential end-users, particular emphasis must be given to aspects such as safety and friendliness of use. Based on the previous assumption, the general philosophy of URMAD was to utilize the best technology provided by the current 'state-of-the-art' and some purposely developed components instead of low cost or existing components which could compromise the system performance (reliability, efficiency, adaptability, etc.) to an unacceptable level. Furthermore, a rehabilitation center (Centro Protesi INAIL, Vigorso di Budrio, Bologna) played an active role in the first stage of the project, when the main requirements of the URMAD system were defined. A consortium was formed to realize the project and the work load was delegated among ten groups (three industrial partners, six universities and one rehabilitation center).

THE URMAD SYSTEM

URMAD is an acronym derived from the Italian words for "Unità Robotica Mobile per l'Assistenza ai Disabili" (Mobile Robotic Unit for the Assistance to the Disabled). The duration of the URMAD project was thirty months (start date April 1992) and the total budget is in the range of two billion Italian lire. The ARTS Lab of the Scuola Superiore S. Anna was the partner responsible for the co-ordination of the project, the development of several subsystems and also completed the final integration of the whole system. The URMAD system is composed of two different main subsystems: a static unit located close to the bedridden user and a mobile unit. The static unit is used to initialize the system, interface with the user, establish and maintain a communication link with the mobile base during the execution of the assigned task. The static unit comprises of a PC workstation (i486/66MHz) equipped with a purposely developed (Windows-like) graphical user interface and a serial radio link to communicate with the mobile unit. The graphical interface, shown in Figure 1, allows the user to command the execution of the desired task simply by using either a mouse or a more appropriate (depending on his/her disability) input device. Additionally, a voice synthesizer presents the confirmation of completed actions and error messages to the user. Depending on the degree of disability of the user, two different modes of operation are supported: if the user is a severely disabled person, the robot can operate in an autonomous mode while more expert users could exploit lower level capabilities by using a teleoperation window. The function of the mobile unit is to receive, interpret and execute user's requests. Contained within the mobile unit, which has planar dimensions of 800 mm, there are batteries, actuators, sensors and an electronic control system. Three independent steering wheels guide the mobile robot, thus providing those fine motion capabilities which are necessary for operation in a partially unstructured domestic environment. The mobile base is equipped with a vision subsystem for navigation composed of two fixed cameras with a dedicated acquisition unit and a processing unit connected by a fast local bus.

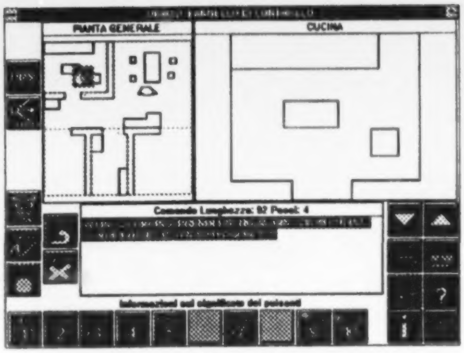


Figure 1: The URMAD graphical user interface

Real-time obstacle avoidance is performed by using both the vision system and a ring of ultrasonic transducers located around the periphery of the mobile unit. Two cameras mounted on a pan and tilt head are used for object and landmark recognition. The mobile unit utilizes VME technology to control its various subsystems. The objects to be manipulated by the robot have known characteristics (shape, dimensions) and their presence in a particular room is assumed *a priori*. The effective localization of an object in a room is performed by the system. The planar map of the environment is assumed to be known, but unknown obstacles might also be present. All the knowledge about the environment is stored in a global data base. Also fixed on the mobile base is an eight degree of freedom arm which has a simple, light weight, kinematically redundant structure and intrinsic safety devices. The end effector mounted on the arm is a three-fingered gripper with integrated tactile sensors on the fingertips. In order to avoid damage to the user, mobile unit or environment, certain safety aspects both from the mechanical and functional perspectives were considered necessary. For instance, the redundant manipulator when not operational is always situated in a folded configuration. Moreover, the robot must be stable in any condition, i.e. during navigation and also during manipulating operations when the base is not in motion. If the radio link ceases to function while the system is executing a user's request the mobile base can continue and complete its current task without any loss of control.

CURRENT STATUS OF THE PROJECT

All the hardware components and software modules of the URMAD system have been implemented and integrated on the first prototype, shown in Figure 2. Figure 3 is relative to the first public demonstration of the URMAD prototype at the BI.M.U. exhibition held in Milan at the end of September 1994.

Figure 2: The URMAD mobile unit.

The preliminary tests have already provided good indications on the viability of the proposed and implemented solution in order to exploit the system to its full potential and guarantee a high degree of autonomy of operation. The mobile unit has been tested successfully in navigation trials in a known environment but in presence of unexpected obstacles, such as humans. The unit has also demonstrated its manipulation capabilities relying on the smoothness of the arm/hand system behavior. Future work will concern extended user trials with severely disabled patients in household and clinical environments in collaboration with the Centro Protesi INAIL (Vigorso di Budrio, Italy), the Italian rehabilitation center joining the project.

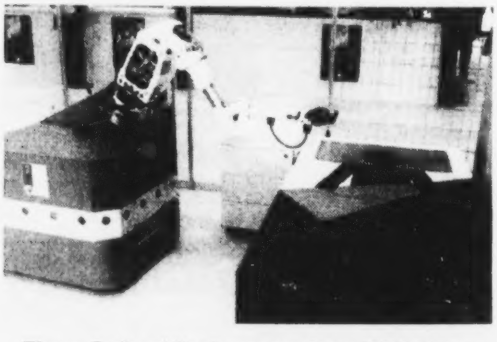


Figure 3: A public demonstration of URMAD at the BI.M.U. exhibition (September 1994).}

DISCUSSION

In this paper, a novel mobile robotic unit for service applications has been presented. Design and development of the various purposely devised innovative components of the system as well as the functional architecture of the whole integrated system have been illustrated. The system demonstrate the effectiveness of the Hi-Tech approach to the problem of assisting the severely disabled. The URMAD system will be exploited for further investigations on basic research issues but it will also be promoted in the near future for direct application in hospitals and large residential institutions. Based on the experience of URMAD, a new mobile unit for genuine domestic application is being currently developed in the framework of a European pre-competitive research project. This robot will be capable of docking into fixed workstations distributed in the environment in order to perform complex tasks which require additional hardware and software computational resources. This solution seems to be a good compromise between the current state-of-the-art and the constrains imposed by the household environment. It is worth to mention that even the single components of URMAD re[resent separate products potentially interesting for research institution as well as for the industrial market.

ACKNOWLEDGEMENTS

The URMAD Project has been funded by the Special Project on Robotics of the National Research Council of Italy.

REFERENCES

[1] Hammel, J., Van der Loos, H., F., M., Perkash, I., (1992). Evaluation of a vocational robot with a quadriplegic employee, Archive of Phys. Med. and Rehabil., 73, 683-693.

[2] Van der Loos, H. F. M., Michalowski, S. J., Leifer, L. J. (1986). Design of an omnidirectional mobile robot as a manipulating device for the severely disabled. Proc. of the 9th Annual Conf. on Rehabilitation Engineering (RESNA), Minneapolis, MN.

[3] Evans J.: (1994) Helpmate: an autonomous mobile robot courier for hospitals IEEE International Conference on Intelligent Robot and Systems (IROS 94), Munich, Germany September 12-16 1994, vol. 3, 1695-1700.

Paolo Dario, Professor of Mechatronics
ARTS Lab - Scuola Superiore S. Anna
Via Carducci 43, 56127 Pisa, Italy
+39-50-883207/560108 (Ph.) / 883215 (Fax)

ANALYSIS AND DESIGN OF AN ARM ORTHOSIS FOR INDIVIDUALS WITH MUSCULAR DYSTROPHY

William Harwin, Sean Stroud, Rungun Ramanathan,.Tariq Rahman and Rami Seliktar.
Applied Science and Engineering Laboratories, University of Delaware /Alfred I duPont Institute,
Wilmington, DE19899.

Abstract

For people with muscular dystrophy and spinal muscular atrophy there is a need for a mechanism to support the weight of the persons arm against gravity and allow either residual muscle force or external power to position the arm in space. The current generation of clinical devices, such as the balanced forearm orthosis (BFO), allows this movement primarily in a horizontal plane. This paper presents one method that allows a person to balance the weight of his or her arm against gravity and thus allows for a wide range of vertical movements.

Careful design of an orthosis based on the mechanism discussed allows the orthosis to be externally powered should residual muscle forces be insufficient to perform the tasks required by the user. A powered orthosis test-bed is described in this paper that allows a variety of power assist ideas to be evaluated. This upper arm orthosis test-bed is based on an RT200 robot.

Introduction

Disabilities such as muscular dystrophy affect the strength of a person's muscle, yet leaves sensation and residual muscular control intact. It is hypothesized that augmenting residual arm function rather than replace it with a robot is a more effective solution for an assistive technology. An ongoing project within the robotics laboratory of the Applied Science and Engineering Laboratories (ASEL) explores methods of augmenting function via a powered orthosis that can support a person's arms against gravity and provide a full range of arm movement. Control of such an orthosis is achieved either by amplifying the person's residual strength or by using signals obtained from other body sites. Residual hand function is important and, although under study within this effort, is not covered in this paper.

Individuals with either total paralysis or absence of sufficient muscle tone for performance of desired arm function are the focus of this study. The aim for the final system is to mount the orthosis on a wheelchair. This decision both suits the needs of the target population and makes the engineering a more tractable proposition.

Background

The terms powered orthosis, extender or orthotic telemanipulator refer to a class of assistive robots that support and move the arm of a person in order to augment function.

The first research on rehabilitation applications of such devices was done at the Case Institute of Technology in the early 1960s [1,2]. A powered exoskeleton was fixed to the floor and controlled via a head mounted light source that triggered light sensors in the environment. This device could do preprogrammed tasks or be moved directly by the individual.[1] This work led to the Rancho 'Golden' arm, developed at Rancho Los Amigos Hospital, in 1969[3]. This was a six degree-of-freedom powered orthosis that used seven tongue switches in a sequential mode to successfully maneuver the arm in space.

The concept of the wheelchair mounted powered orthosis resurfaced in the U.K. in 1987 when Hennequin presented a prototype powered arm support that used a novel pneumatic actuator to assist movements of the person's right arm [4]. The device was controlled by direct control of the actuator joints via a switch pad operated by the person's left hand. This project was transferred to the design center of the Engineering Department at Cambridge University U.K. where it became a design project intended to evaluate new design methods. This orthosis moves the persons arm against gravity while allowing unconstrained arm movements in the horizontal plane [5].

The Balanced Forearm Orthosis (BFO) developed in the fifties is currently the most popular body powered orthosis in clinical use. The basic design limits the person to working in a horizontal plane, although the balance point does allow a skillful person to reach his or her mouth to assist with eating.

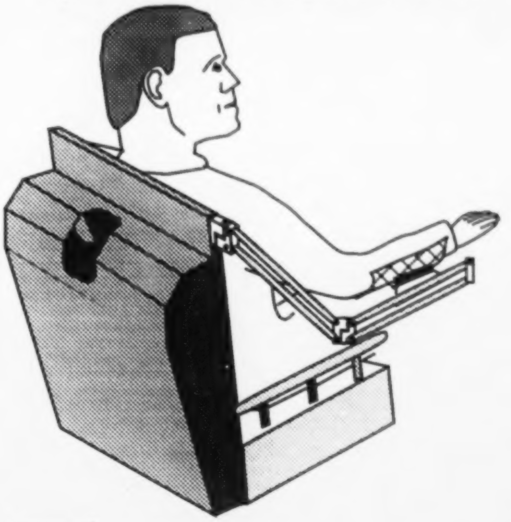
Objective

This project intends to create the engineering knowledge for a range of body and externally powered orthosis designs that are modular and mount on the person's wheelchair.

This engineering knowledge must relate the device to the way it is used. Further, the success of such a device depends on the interface between the person and the machine and it is vital that the person is able to predict the behavior of the device during operation. Understanding of this interface is a further goal of this research and a test-bed is used to prototype and evaluate interface strategies.

Evaluation of the kinematic and aesthetic concept done via a series of virtual and physical prototypes that allow directed and appropriate feedback from consumers (users, families, care-givers and clinician). Methods must be developed to ensure this is done in a cost effective manner. An initial concept drawing of what the eventual device might look like is given in Figure 1.

Figure 1: Concept drawing of arm orthosis



Approach

A key element of this project is the timely and appropriate input in the design process of the end users of the target product along with the family, care-givers and rehabilitation professionals.

In April and July of 1994 a forum for ideas was initiated where children with spinal muscular atrophy and muscular dystrophy and their families and care-givers were invited to participate in a series of brainstorming sessions to identify areas of need and the potential of an upper arm orthosis to meet these needs. The results of this focus group are documented in a Technical report [6].

Among the concerns expressed by consumers was simplicity and portability of any robotic device. There are also clear advantages to augmenting existing functions rather than attempting to replace function with a robot when a person retains some residual motor and sensory function. Moreover, even when such sensory function is absent, the psychological merit of the use of an orthosis versus a purely robotic system is important.

Results

Body Powered Orthosis Design

The underlying mechanism proposed for the design of a practical upper arm orthosis is shown in Figure 2. Either a static analysis or energy methods can be used to show that given a linear spring

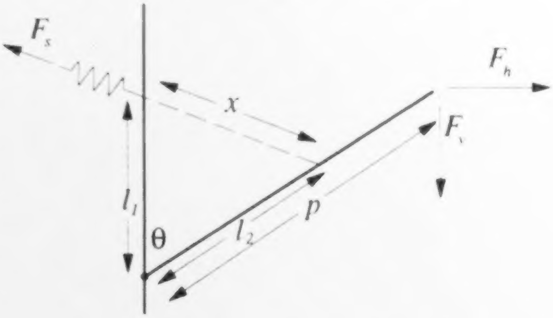
$$F_s=K_0\,(x-x_0)$$

where F_s is the spring force, x_0 is the rest length of the spring, and K_0 is the spring constant, the system is in equilibrium when

$$\frac{K_0 l_1 l_2}{p}\left(1-\frac{x_0}{x}\right)=\ (F_v+F_h\cot\theta)$$

Two terms in this equation depend on θ, $F_h\cot(\theta)$ and x_0/x. Both these terms can be designed out of the mechanism, by minimizing horizontal forces, and by arranging for $x_0=0$. The remaining force, F_v, consists primarily of the weight of the person's arm along with any residual forces that are used to move the mechanism up and down, i.e. $F_v=Mg+F_r$.

Figure 2: Static analysis of mechanism



This results in the weight of the person's arm being supported by the mechanism independently of the position of the arm. Additional properties can be intentionally added to the mechanism. For example an additional load can be accommodated by adjusting l_1 or l_2, likewise a controlled stiffness can be induced by having a non zero value for x_0.

Practical considerations however dictate some compromises. For example, the spring may have non-linear characteristics and the mechanism's kinematics must be aligned with the kinematics of the person's arm.

Three physical prototypes have been developed, similar in shape to the concept drawing shown in Figure 1. These prototypes have demonstrated the feasibility of this approach and have received limited informal evaluation. Work is now progressing towards a prototype mechanism that can be taken through a more formal short term clinical evaluation.

Externally Powered Orthosis Test-bed

A body powered orthosis is likely to be effective for people with certain classes of disabilities but does not fulfill all the requirements of a device intended to assist people with degenerative muscular conditions such as muscular dystrophy. The design of the body powered arm orthosis should have the necessary modularity so that actuators can be added to accommodate for progressive loss in function. To meet this design goal, and establish human machine interface criteria for an external power assisted orthosis, a test-bed has been established based on a modified SCARA robot arm. This test-bed, built on an RT200 (Oxford Intelligent Machines Ltd. UK) can simulate a wide range of possible powered orthosis configurations. The gripper of the robot has been replaced with a force sensor and an arm support. Software was written that measures residual forces generated by the person on the orthosis and uses these forces in the control structure.

A variety of relationships between the exerted force and the movement of the orthosis have been evaluated such as relating force to position, force to velocity and force to acceleration. More complex relationships have also been developed such as relating impulse to velocity via a pseudo mass.

This test-bed was demonstrated at the 1994 focus group meetings. Children with spinal muscular atrophy and muscular dystrophy were invited to use this test-bed in a number of ways. They were all impressed that they could move a large and powerful machine with a minimal force.

The flexibility this test-bed allows in prototyping the human machine interface has been valuable in assessing the design of both the body and the external powered orthosis. It has highlighted the need to understand the conditions for stability for an orthosis, and has shown how an intuitive interface can be established. Further areas of exploration with this test-bed include prototyping and assessing different interfaces strategies.

Discussion

The use of a test-bed has proved a valuable method to assist with the design of a powered upper arm orthosis. Although certain aspects of the body powered mechanism are difficult to prototype, such as dynamic behavior, the test-bed does allow us to assess possible ranges of motion and the need for gravity compensation. It also allows evaluation of interface strategies for an external powered orthosis. These ideas can then be incorporated in the designs of the body powered orthosis. A practical clinical upper arm orthosis design is ongoing at the ASEL based on the sine mechanism. The design is intended to be modular so that external actuators can be added if needed to account for the progressive loss of strength because of a disease such as muscular dystrophy.

References

[1] Maurice LeBlanc and Larry Leifer. *Environmental control and robotic manipulation aids. Engineering in Medicine and Biology Magazine*, pages 16–22, December 1982.

[2] James B. Reswick. *The moon over Dubrovnik - a tale of worldwide impact on persons with disabilities.* In *Advances in External Control of Human Extremities*, Dubrovnik, 1990.

[5] Bauert, F. *The Mobile Arm Support Phase I: Design, Manufacture, Testing.* Technical Report CUED/C-EDC/TR 13, Cambridge University Engineering Department. 1993

[3] James R. Allen, Andrew Karchak, Jr., and Ernest L. Bontrager. *Design and fabrication of a pair of Rancho anthropomorphic arms.*Technical report, The Attending Staff Association of the Rancho Los Amigos Hospital, Inc, 1972.

[4] Jim Hennequin, Robin Platts, and Yvonne Hennequin. *Putting technology to work for the disadvantaged.* In *Rehabilitation Robotics Newsletter*. The Rehabilitation Robotics Research Program, Applied Science and Engineering Laboratories, Alfred I. duPont Institute and the University of Delaware, 1992. vol 4(2).

[6] Rungun Ramanathan, Sean Stroud, and Michael Alexander. *Powered orthosis project forum.* Technical Report ROB9405, Applied Science and Engineering Laboratories, P.O. Box 269, Wilmington, Delaware, USA, 1994.

Acknowledgments

The authors are pleased to acknowledge funding from the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, Grant #H133E30013, the Rehabilitation Engineering Research Center on Rehabilitation Robotics. Additional support is provided by Nemours Research Programs.

Author address

Dr. William Harwin, Applied Science and Engineering Laboratories, University of Delaware /Alfred I duPont Institute, P.O.Box 269, Wilmington, DE19899.

AN EVALUATION OF RESIDUAL SHOULDER FUNCTION AS AN INPUT TO A VARIABLE-IMPEDANCE ASSISTIVE ROBOTIC SYSTEM

David Fass, B.S.*†‡, Tariq Rahman, Ph.D.*‡, and Rami Seliktar, Ph.D.*†‡

*Applied Science and Engineering Laboratories, Alfred I. duPont Institute (and the University of Delaware)
†Department of Mechanical Engineering and ‡Biomedical Engineering and Science Institute, Drexel University

Abstract

Post-spinal cord injury residual shoulder function is being investigated as an input to a master-slave assistive robotic system based on extended physiological proprioception (EPP). This work complements a concurrent investigation of head/neck control of an assistive EPP-based robotic system, and is motivated by the successful implementation of the EPP concept in shoulder-controlled prostheses. Pursuit tracking tasks are being used in conjunction with a variable-impedance haptic interface to study the dependency of shoulder performance on task frequency content, practice, and the compliance/damping level of the interface. Preliminary findings indicate that while tracking capability at the shoulder is inferior to that at the hand, there is potential for the shoulder to offer a useful control site in a manipulation system.

Background

The mechanism of extended physiological proprioception (EPP), by which the human nervous system is able to accomplish the natural and instinctive *manual control* of tools and devices, has been recognized as being a critical determinant of the usefulness of prostheses [1-6]. The role of extended physiological proprioception in the successful implementation of man-machine systems is now being reconsidered in the context of assistive robotics for the disabled [3,4]. At present, an assistive robotic system which is both versatile and natural to use represents an ideal which, in engineering practice, has been difficult to achieve. Assistive robotic implementations have tended to be polarized toward either a supervisory control philosophy or an operator/controller concept. In removing the user from the control loop, the supervisory arrangement sacrifices versatility for *ease-of-use*, while it is *versatility* which is preserved in the operator/controller design at the expense of a heavier operator work-load (which typically involves low-level control of a multi-degree-of-freedom end effector).

This sacrifice of ease-of-use for versatility, and its deleterious affect on practical robot functionality, is a consequence of the reliance upon a very narrow communication channel between user and robot, one which does not naturally transmit the dynamical information necessary for the user to experience EPP. However, in both industrial and research settings, robotic manipulation tasks which require a human operator in the loop together with precision and dexterity at the end-effector have been successfully addressed with telemanipulation technology, including systems in the bilateral, force-reflecting, master-slave configuration. It is an identical technique whose application to assistive robotics for individuals with high-level spinal cord injury (SCI) has been previously described [4]. For individuals with a C-5 functional level, the head (roll, pitch, yaw) and shoulders (protraction/retraction and elevation/depression) are viewed as candidates to provide the control input to such a robotic system; that is, to be mechanically interfaced to the *master* aspect of the master-slave system.

The head and shoulder are not equally appealing as control sources, however. The head, as an integral aspect of its normal function, performs tracking- and targeting-type tasks for positioning the mouth, directing the gaze, etc., so that the desired qualities of a control source for a manipulation system are clearly present at this site. In contrast, the shoulder's normal role as a stable support for movement of the arm does not often require this degree of tracking ability to be exhibited in isolation of arm movement by, for instance, the lateral aspect of the clavicle. In addition, a severe limitation of the range and resolution of shoulder movement in SCI individuals relative to non-disabled test subjects has been described by Johnson and Peckham [7]. It is therefore not clear whether the level of function available at the shoulder of an SCI person will be adequate to provide an effective control input for a manipulation system.

Research Question

There are a number of issues to be addressed in this context, with the primary concern being how well the shoulder of an individual with C-5 level SCI can perform the movements which would be required for it to be an effective control source for one or two degrees-of-freedom of a manipulation system. Making such an assessment requires a definition of what is considered to be "adequate" performance of a control source, and a determination of how this is measured. Additionally, in consideration of the fact that the control site on the body is to be mechanically coupled to the master robot, which can therefore be viewed as the "control" to be operated by the user, attention must be given to the impact of control parameters (compliance, damping, and inertia) on the performance measured. In particular, the damping and compliance (i.e. self-centering behavior) of a control have been shown to impact favorably upon compensatory tracking performance seen for the arm and hand [8]. The possibility of improving shoulder performance through the tuning of these control parameters requires investigation as well.

Method

To explore these aspects of shoulder performance, a variable-impedance haptic test device, the Shoulder Interface Mechanism (SIM, Figure 1), was designed to interface with a subject's right shoulder. To avoid any impairment of shoulder mobility by the test apparatus, a minimal shoulder harness is used which includes a conformable rubber pad adhered to the skin on the top of the shoulder and a single strap under the arm to supplement the adhesive. (The attachment site is positioned as far laterally as possible to take advantage of the clavicle's greater range of motion there.) Freedom of movement of the shoulder is thus preserved at the expense of introducing a greater interface compliance in the horizontal direction due to the sliding of the skin over the bone. The SIM is a parallel linkage actuated by two electric motors driven by HCTL 1000 motor control chips, and carries a two-axis force sensor above the shoulder harness. In use, the SIM behaves as a passive load coupled to the operator's shoulder, following the force applied by the shoulder to the harness force sensor in a manner determined by the compliance and damping properties established for it by the microcomputer controller. The computer controller samples the force sensor and the optical motor encoders and commands the motor control board at a rate of approximately 33 Hz.

Shoulder performance will be assessed through a variety of tracking and targeting tasks (scaled to each subject's range of motion) which are chosen to be representative of the variety of movements the shoulder might be called upon to make as a control source in a manipulation system. Tasks currently being tested on the system include sinusoidal radial and helical pursuit programs of various frequencies (Figure 3), and acquisition of a randomly (in space and time) appearing fixed target. During testing, position, velocity, and force data is recorded from the SIM by the computer at a rate of approximately 17 Hz. The data obtained from testing of disabled and non-disabled subjects will be studied for correlation between tracking error and task frequency, SIM impedance property (damping and compliance levels), and familiarity with the test (practice). Additionally, for the non-disabled test subjects, data will be collected for performance with the arm and hand (in place of the shoulder) on the same tasks, for which purpose a joystick-type handle is fitted in place of the shoulder harness (Figure 2).

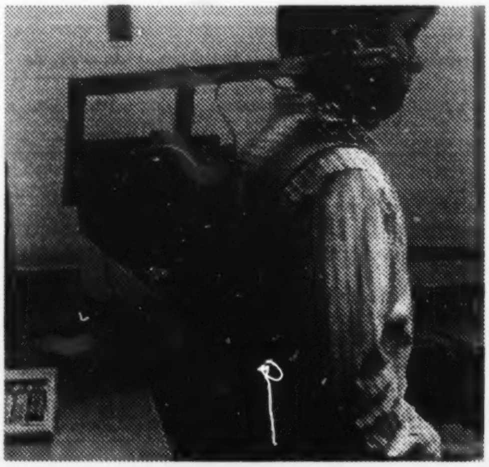


Figure 1. Shoulder Interface Mechanism (SIM).

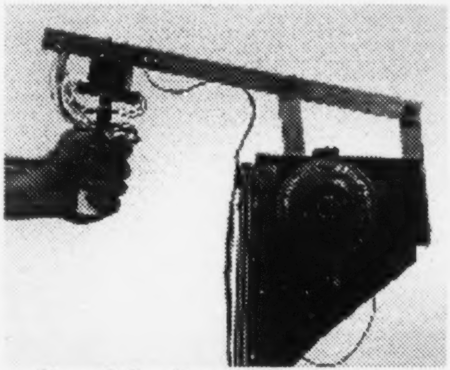


Figure 2. Tracking with Hand and Arm.

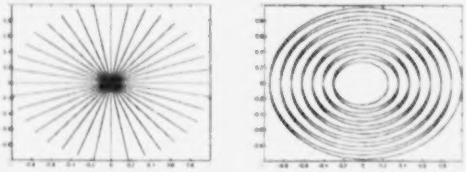


Figure 3. Radial and Helical Pursuit Tracking Tasks.

SHOULDER FUNCTION AS INPUT TO A ROBOTIC SYSTEM

Preliminary Results

The results of a single-subject (non-disabled and familiar with the test) set of 0.25 Hz radial pursuit tracking trials are shown below (Figure 4), during which both hand and shoulder tracking were performed at two different levels of control damping (with zero compliance). The higher level of damping in these trials is approximately twice the lower, which in turn is a minimal level yielding a very light control feel during slow movements. The figure shows the *x* (positive in the direction of shoulder protraction) and *y* (positive in the direction of shoulder elevation) coordinates of the target presented on-screen during the test, as well as the magnitudes of the tracking errors for the four cases. The diameter of the circular region traversed by the target was approximately 3 inches. The mean errors are 0.1406 in. for shoulder control under low damping, 0.1641 in. for shoulder control under high damping, 0.0971 in. for hand control under low damping, and 0.0980 in. for hand control under high damping.

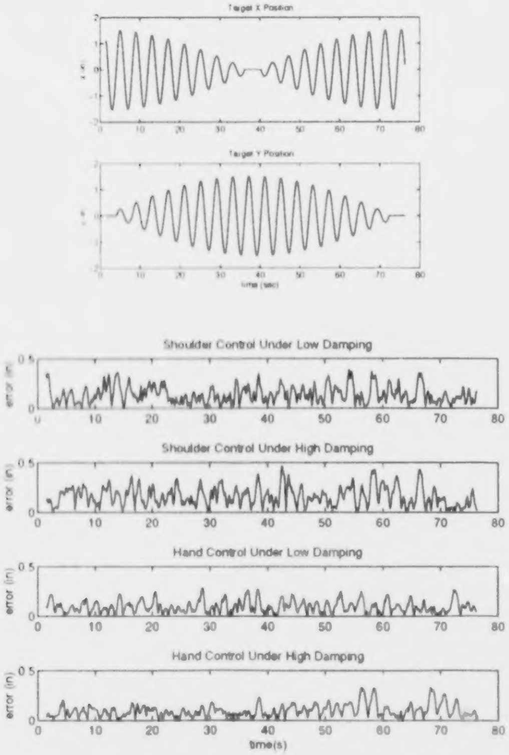


Figure 4. Target Position and Tracking Error Magnitudes in a 0.25 Hz Radial Pursuit Task.

Discussion

Although there is not an obvious impedance-dependence in this particular data set of the type which is expected to emerge from planned testing (which might be reflective of the equalizing effect of *practice* reported in [8]), there is an indication of the inferiority of shoulder performance with respect to hand performance. It is also clear, though, that there is valid reason to consider the shoulder a viable site for control input, and to continue with the evaluation of shoulder performance for SCI individuals. Data collected during formal trials will be analyzed for additional time-domain (lead/lag behavior and spatial/directional dependencies) and frequency-domain characteristics to provide a complete quantitative picture of shoulder capabilities and their relationship to control impedance.

Acknowledgments

This work was performed at the Applied Science and Engineering Laboratories of the A.I. duPont Institute, and was supported by the Nemours Research Programs, and by Fellowships from E.I. Du Pont De Nemours & Company, and the Drexel University Calhoun Fund.

References

[1] J. A. Doubler, "An Analysis of Extended Physiological Proprioception as a Control Technique for Upper-Extremity Prostheses," Ph.D. thesis, Northwestern University, Evanston, IL, June 1982.

[2] J. A. Doubler and D. S. Childress, "Design and Evaluation of a Prosthesis Control System Based on the Concept of Extended Physiological Proprioception," *Journal of Rehabilitation R&D*, vol. 21 no. 1, 1984, pp. 19-31.

[3] C. W. Heckathorne, "Manipulation in Unstructured Environments: Extended Physiological Proprioception, Position Control, and Arm Prostheses," *Proceedings of the 1990 International Conference on Rehabilitation Robotics*, Wilmington, DE, 1990, pp. 39-54.

[4] J. Wunderlich, S. Chen, D. Pino, T. Rahman, and W. Harwin, "Software Architecture for a Kinematically Dissimilar Master-Slave Telethesis for Exploring Rehabilitation Applications," *Proceedings of the SPIE-93*, Boston, MA, October 1993.

[5] D. C. Baer and R. Seliktar, "Arm Prosthesis for Above-Elbow Amputees, Based on Extended Physiological Proprioception," *Proceedings of the IEEE, EMBS, 9th Annual Conference*, Boston, MA, November 1987.

[6] T. Rahman, "Control of a Prosthetic Arm Using Coordinated Movements of the Shoulder," Ph.D. thesis, Drexel University, Philadelphia, PA, December 1990.

[7] M. W. Johnson and P. H. Peckham, "Evaluation of Shoulder Movement as a Command Control Source," *IEEE Transactions on Biomedical Engineering*, vol. 37 no. 9, September 1990, pp. 876-885.

[8] D. Howland and M. E. Noble, "The Effect of Physical Constants of a Control on Tracking Performance," *Journal of Experimental Psychology*, vol. 46 no. 5, 1953, pp. 353-360.

David Fass, Applied Science and Engineering Laboratories
Alfred I. duPont Institute, P.O. Box 269, Wilmington, Delaware 19899
Tel: (302) 651-6830, Fax: (302) 651-6895, e-mail: fass@asel.udel.edu

SIG-14
Job Accommodation

MODIFICATION OF OFFICE CHAIR CONTROLS FOR INDIVIDUAL WITH LIMITED UPPER EXTREMITY MOVEMENT

Glenn Hedman, M.Eng.
Coordinator
Assistive Technology Unit / Institute on Disability and Human Development / University of Illinois at Chicago

ABSTRACT

In an attempt to respond to consumer demand for more ergonomic features in commercially-available office chairs, manufacturers are offering models having several adjustable settings. Access to controls of these features is a problem for individuals with limited upper extremity function. A commercially-available office chair having adjustable seat-to-back angle, seat height, and tilt-in-space was modified to enable an individual with bilateral arthritis and low back pain to independently operate the controls while in a seated position.

BACKGROUND

Manufacturers of office chairs have responded to the call for greater ergonomic adjustability in their products. While poor chairs are still available, many office chairs offer some user-adjustable settings, and mid-range chairs commonly offer an array of adjustments.

Access to the activation controls of the adjustable features remains a problem, however, for individuals having limited back mobility or upper extremity function. Since the adjustable features, once "unlocked", are manipulated by the body weight or position of the user, any great variation from a common, upright posture may mean that the feature is inaccessible.

Referral was made from a local commuter railway corporation for the provision of a reasonable accommodation through the Americans with Disabilities Act. Specifically, a senior lawyer with the corporation requested accommodation of her workstation chair to address her low back pain and bilateral upper extremity arthritis. The lawyer, seated for long periods of time while reading materials, talking on the telephone, and working at a computer, requested upgrading of her office chair to enable these activities to be performed without discomfort. After review by the corporation's ADA compliance committee, authorization was made for the provision of Worksite Modification Evaluation services.

OBJECTIVE

The goals of the service included the provision of an improved office chair which had the adjustable features that the client needed, the external modification of the chair controls to keep the design simple and maximize the opportunity to transfer the modification to another chair, and the minimization of the cost involved.

METHOD / APPROACH

A Worksite Modification Evaluation was performed by a Rehabilitation Engineer, for the chair / workstation issues, and an Occupational Therapist, for the computer issues. The client's existing chair was examined and was found to have virtually no easily adjustable features. Seat height could be adjusted, but only by spinning the unloaded chair until the desired seat height was achieved. The chair had armrests, but they were at a fixed height and positioned too low to offer support for the client's upper extremities.

A commercially-available chair was brought in for trial use during a typical workday. The chair had adjustability in the areas of seat height, seat-to-back angle, tilt-in-space, and armrest height. The back of the chair was shoulder-height, as per the client's preference.

The adjustable features of the chair gave the client the ability to achieve a more upright position while working at her desk, and gave her the flexibility to change her position throughout the day. For instance, the client could adopt a more reclined position while reading through materials.

While the adjustable features of the chair met the client's needs, the controls to make those adjustments possible were inaccessible to her. Use of the existing controls required her to lean laterally to the right, lift the appropriate release lever, and shift her weight suddenly once the feature was unlocked to adjust it. This was an awkward task to perform, and did not lend itself to maintaining concentration on the work task at hand, nor the interaction with clients.

MODIFIED OFFICE CHAIR CONTROLS

A preliminary design regarding the modification of the chair for independent use by the client was sketched out. The overall cost of the adapted office chair was submitted to the corporation in a Worksite Modification Evaluation report, and the prior approval for the provision of the adapted chair was obtained.

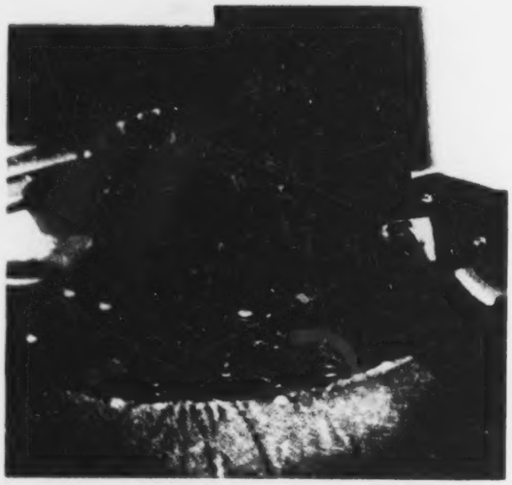
Three activation levers are present below the right side of the seat. The rear lever controls the seat-to-back angle, the middle lever controls the seat height, and the front lever controls the tilt-in-space.

Modification of the middle lever was achieved by contouring two pieces of 3/16" x 1" aluminum bar into L-configurations, and joining the two along their length using a series of holes. The adaptive lever was then attached to the paddle-like end of the existing plastic lever. The exact height needed for the top section of the resulting Z-configuration could then be adjusted at the worksite, if necessary.

Modification of the rear and front levers was more involved. Each of the existing molded plastic levers had a cam-shaped cross-section on the proximal end, which pushed onto the end of a spring-loaded, threaded bolt. The shoulder of this bolt rested on the slotted groove of a stack of metal links. The release of the grip on the slotted opening in the links enables the adjustment of the back angle or tilt-in-space. Thus, another means of slightly displacing the end of the bolt needed to be devised, one that would enable the client to operate the control with her existing upper extremity abilities from a typical seated position. The design decision was made to try to provide this displacement through the rotation of a threaded rod.

Removal of each plastic lever left a cylindrical housing having outside diameter 1.125" (Figure 1). A two-piece shaft coupling was obtained with a 1.125" inside diameter, and overall length of 3.125". This shaft coupling was able to attach to approximately 3/4" of the chair cylinder housing, leaving 2.375" of the inside diameter length to clamp to components supporting the threaded rod.

Two thumbwheels, having outside diameter 1.125" and inside threaded diameter 1/2"-13, were inserted into the open length of the shaft coupling. A 12" length of 1/2"-13 stainless steel rod was threaded into the thumbwheels, enough to come in contact with the end of the threaded bolt (Figure 2).



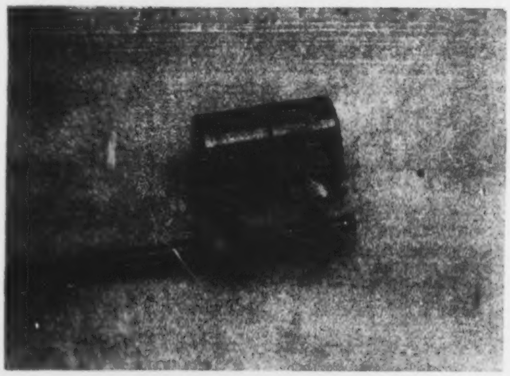


Figure 2

At the distal end of the threaded rod, a single 1/2"-13 threaded coupling was sandwiched between two, two-piece threaded shaft collars. This provided the attachment location for two closed-end wrenches. One wrench was oriented upward for use by the client, one was oriented downward and weighted with surplus bearings to provide a counterweight. Black cylindrical foam was added to the wrenches for aesthetics (Figure 3).

Activation of the control, and release of the grip on the adjustment links, was achieved by moving the top wrench from an "11 o'clock" to "1 o'clock" position (Figure 4).

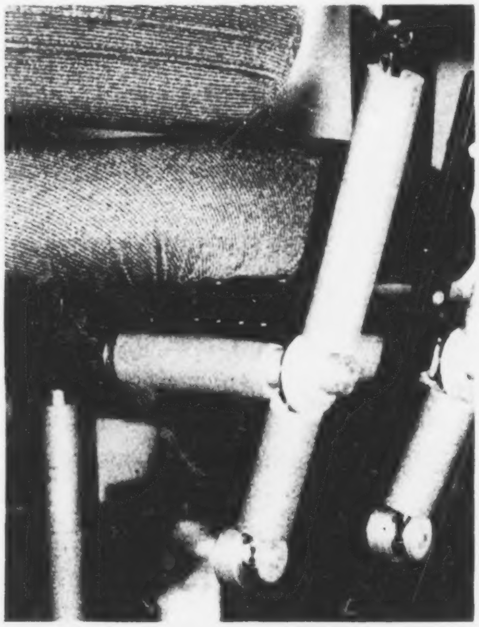


Figure 3

Figure 4

RESULTS

With the modifications to the three controls in place, the client was able to independently adjust the height of the seat with respect to the floor, the back angle with respect to the seat, and the tilt-in-space position of the entire seat and back with respect to the floor. The client was able to perform these adjustments while in a neutral position in the chair, without having to lean to the side to access the controls.

DISCUSSION

While the availability of adjustable office chairs has increased greatly in the past few years, their use by individuals with disabilities cannot always be assured unless adaptations are made. In this case, a commercially-available office chair, having the ergonomic features needed by the client, was adapted to enable the client to access all controls. Adaptation of the seat height adjustment control was fabricated from raw materials, adaptation of the more complicated seat-to-back angle and tilt-in-space controls was achieved through the use of commercially-available parts.

SOURCES

Office chair
Global Industries, Inc.
Model 4432

Shaft couplings
Ruland Manufacturing Co., Inc.

Thumbwheels
Threaded rod
Threaded couplings
Threaded shaft collars
McMaster-Carr Supply Company

Wrenches
Sears Industrial Sales

Insulating foam
Local hardware store

ACKNOWLEDGEMENTS

Support for the application of Worksite Modification Evaluation and Implementation services was provided by METRA, Inc.

Glenn Hedman
Coordinator
Assistive Technology Unit
Institute on Disability and Human Development
(UAP) (M/C 626)
University of Illinois at Chicago
1640 West Roosevelt - Room 412
Chicago, IL 60608-6904
(312) 413-7784 (Direct desk)
(312) 413-1555 (ATU main office)
(312) 413-1554 (TTY)
(312) 413-3709 (FAX)

THE MODIFICATION OF INDUSTRIAL EQUIPMENT TO ENABLE A PERSON WITH A SEVERE DISABILITY TO WORK

Jess P. Gonzalez, Nigel Shapcott
Assistive Center for Technology/Human Management Resources,
Washington, PA
and University of Pittsburgh, School of Health and Rehabilitation Sciences,
Pittsburgh, PA

ABSTRACT

This paper describes a job accommodation at a recycling center to enable an individual with a diagnosis of Cerebral Palsy (CP) to operate a machine which compresses metal cans into cubes which are then sold. For the economy to provide services and devices directed to the disabled consumer, the economic empowerment of people with disabilities needs to be optimized. The primary means for economic empowerment is through the availability of employment with fair economic remuneration. Therefore the availability of jobs available to people with disabilities needs to be expanded. One way to expand employment opportunities for people with disabilities is by the creative and cost effective application of technology to increase the number of jobs suitable for people with disabilities.

BACKGROUND

The Assistive Center for Technology (ACT) has developed an Assistive Technology service with a mobile evaluation and work site modification component. ACT works closely with the Pennsylvania Office of Vocational Rehabilitation, Washington Pa. District Office to provide solutions to people with disabilities wishing to seek gainful employment.

In an effort to expand the availability of jobs for the more severely disabled population we were asked to investigate the possibility of developing jobs at a newly opened recycling center run by Goodwill of Uniontown, Pa. Two OVR clients with severe disabilities who lived locally to the recycling plant were identified as candidates for working there. One of these individuals was subsequently dropped as a candidate for this position because of attendant requirements related to medication issues.

On our initial visit to the site we identified the densifier machine as a possible position. The densifier machine takes metal cans, either aluminum or steel and compresses them into 18"x 12"x 12" cubes known as biscuits (figure 1). As the machine produces the biscuits they are expelled onto the floor at a rate of about one every two minutes. The biscuits weigh approximately 30-60lbs each depending on whether they are aluminum or steel. Subsequently the biscuits are stacked by hand beside the machine. It was undesirable to have someone stack the biscuits manually because of the risk of back injuries and cuts to the hands and arms from the many sharp edges inherent in this product.

PROBLEM STATEMENT

It was determined that if the stacking of the cubes could be automated and the densifier controls modified then an operator position for the client in question would be feasible. The technical challenges associated with modifying the densifier machine were as follows:

1. Automate the stacking and storage of the densifier output.
2. Design the machine controls for operation by someone with only gross movement.
3. Make the controls accessible to someone in a wheelchair.
4. Create an area that would be safe and comfortable for the operator.
5. Within these parameters to keep the design as simple as possible to ensure:-
high system reliability
costs kept to a minimum
minimize the extent of the modifications and any production disruptions on site.

DESIGN CONCEPT

The operator position was designed for a 32 year old individual with CP who uses a wheelchair. Before the design portion was started we meet with the individual to ascertain his level of function. After this information was gathered the design work was started. Although the machine modifications were to be designed with a certain individual in mind we wanted the changes to be as generic as possible to allow for other individuals with reduced function to be considered for the operator position if need be.

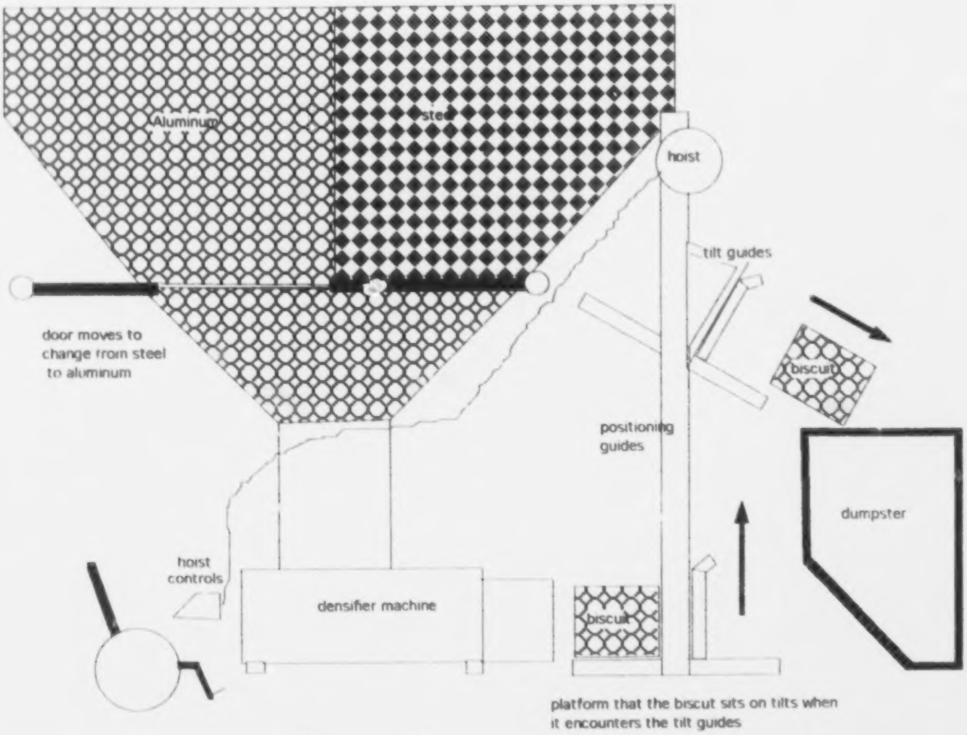

Aluminum
steel
hoist
tilt guides
biscuit
door moves to change from steel to aluminum
positioning guides
dumpster
hoist controls
densifier machine
biscuit
platform that the biscut sits on tilts when it encounters the tilt guides

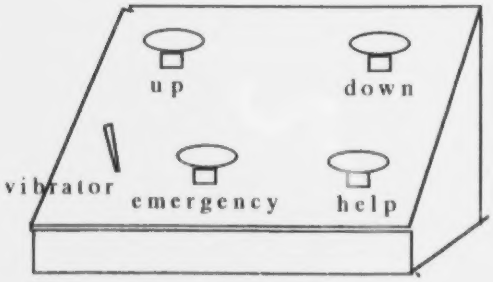
FIGURE 1

The concept developed into an electrically operated lift which would feed the biscuits into a dumpster of appropriate capacity to allow for reasonable work times between removal and storage. The design should incorporate a signal suitable for a noisy industrial environment to alert the fork lift driver of the need to move the full dumpster and bring an empty. The design should also be relatively straightforward to install to minimize disruption of production incorporate into the design. Any mechanical failure of the lift should not cause disruption of production which could not be overcome by resorting to short term manual handling.

DESIGN SOLUTIONS

To automate the stacking and storage of the biscuits a simple lifting and dumping machine was designed. The machine consists of a hinged platform lifted by a standard 1/2 ton hoist. The platform is kept on location by 2 parallel 3 x 3 x 1/4 inch angles. These angles also act as the supportive framework for the machine and the hoist. The lift/tilt platform was fabricated from 2 x 2 x 1/8 inch angle. The hinged platform was attached to two 12 inch pieces of 3 x 3 x 1/4 inch angle to act as guides that would run within the 3 x 3 x 1/4 frame work. When a biscuit is expelled from the densifier it lands on the machine lift/tilt platform. The hoist is then activated by the operator. As the lift/tilt platform rises along guide angles it encounters two tilting guides which tilt the platform and dump the biscuit into the dumpster (see figure 1). This configuration eliminated the need for any linear motion other than a straight vertical lift, thus simplifying the design and ensuring a high likelihood of system reliability.

Because the primary function of the position would be to load the biscuits into the dumpsters the hoist motor controls needed to be designed for ease of use. One cycle of the operation is as follows: once the momentary up switch is activated by the operator the hoist is energized, lifting the lift/tilt platform to the required height and dumping the biscuit. Then the hoist limit switch is activated which de-energizes the hoist. Next the down cycle is started by the momentary depression of the down switch by the operator. The hoist then lowers the lift /tilt platform to receive another biscuit.



Control Panel

figure 2

Along with the up and down switches are an emergency shut down switch, in case of a malfunction, and a switch that activates a yellow strobe light. The strobe light is used when the operator needs to summon the fork lift to empty a dumpster or if the operator needs assistance. A separate small toggle switch operates a small vibrator that shakes down the cans. The vibrator is activated once or twice a day. All the other switches are 2.250 diameter momentary mushroom switches. The switches and hoist control circuitry are mounted in a 11" x 13" x 9" enclosure with a sloping front (see fig. 2). The enclosure is mounted on a fully adjustable movable stand which was custom fabricated.

An enclosed area that would help control the temperature, contain the machine controls and provide a clear safe area for the operator was also required. The operator area was enclosed with a plywood roof and clear vinyl strips on three sides, these provide good visibility, reduce drafts and allow for easy wheelchair access.

RESULTS

After the modifications were made the client was brought in for a test run. Adjustments were made to the control box stand to better position it for the operator. Within minutes he understood the operation of the machine and was successfully operating the hoist controls. The client is now training three days a week to build up his stamina and to work out clothing and attendant care strategies. As of this writing the modification are performing well and the client is expected to start full-time after 30 days.

Total cost for the modifications was $11,000.

ACKNOWLEDGMENTS

Although we performed the technical work required this successful job placement was the result of a collaborative effort by the people at the Goodwill recycling center, Goodwill case mangers, the Office of Vocational Rehabilitation, and attendant care providers.

- Pennsylvania Office of Vocational Rehabilitation, Washington District Office;
-Assistive Technology Center/Human Management Resources, Washington;
- Goodwill Industries, Uniontown;
- University of Pittsburgh, Center for Assistive Technology, School of Health and Rehabilitation Sciences.
Jess Pelligrino , Motor controls

Jess P. Gonzalez,
Assistive Technology Center,
Human Management Resources,
1174 Findlay Street,
Washington, PA 15301

CUSTOM JOBSITE ACCOMMODATIONS: TWO CASE STUDIES

Patti Barrett
Department of Labor and Employment Security
Division of Vocational Rehabilitation
Tallahassee, Florida, USA

ABSTRACT

This paper discusses custom worksite accommodations to enable two people with severe physical disabilities, employed by the state, to be productive workers. In the first case study, an alternative low-tech file system and custom workstation was developed for a C-5 quadriplegic who was unable to access a lateral file cabinet. In the second case study, a custom workstation and lateral file cabinet riser were designed to enable a woman of short stature (3'6" tall) with Osteogenesis imperfecta to access her work environment.

BACKGROUND

Employment related obstacles to performance and productivity may be solved through the use of assistive technology. Assistive technology may range from using commercially available products to custom designed devices. A creative approach is necessary as each individual is as unique as the accommodation required.

In designing work environments for people with disabilities, the assistive technology must match the user's physical capabilities, be aesthetically appealing, and fit into the person's assigned work space or office. The following case studies provide examples of accessible work environments created after analyzing the employee's job tasks.

OBJECTIVE

CASE STUDY 1

The objective was to enable Robert, a C-5 quadriplegic, employed by the state as a Public Assistance eligibility determinator manipulate and file cases.

Robert's files were placed in a file holder mounted on his office door which he was unable to reach from his wheelchair. The file holder was lowered to a wheelchair accessible height. He was also experiencing difficulty lifting the files out of the file holder box and carrying them to his desk. A light weight clear plastic pouch with 2 rip stop nylon semi-rigid handles was designed to rest in the bottom of the new lowered door mounted file holder. Robert was then able to lift the pouch with the file and transport it to his desk which wasn't accessible.

Next, a custom workstation incorporating a lazy susan type file holder was designed to accommodate Robert's wheelchair and provide an efficient work area to manage his large case load.

Robert was unable to access his four drawer vertical file cabinet from his wheelchair. Lateral file cabinets weren't an option, due to his wheelchair and the narrow size of his office (13'L x 7'6"W) yet, maximum file storage was required. As the files didn't have to be secured under lock and key, open shelves with wire dividers, at wheelchair accessible height, were mounted on two walls of his office. This custom designed shelf system enabled Robert to manage his files without compromising his limited office space.

CASE STUDY 2

The objective was to enable Jan, a woman of short stature (3'6" tall) with Osteogenesis imperfecta, who ambulates using a power wheelchair, employed by the state as a Client Advocate, access her work environment. A custom workstation was designed to enable her to be more efficient, organized, and productive at her job.

The workstation, sized down to fit Jan, incorporated electrical outlets in the legs with a power switch mounted near the center drawer. Two legal size file drawers were located on either side of the workstation with the handles placed vertically to accommodate her hand dexterity. Her computer was placed on one lazy susan and her files were placed on a second lazy susan, located on opposite corners of the workstation. A specially designed platform, covered with laminate to match the workstation, was positioned under her existing two drawer lateral file cabinet to enable her to access both file drawers.

DISCUSSION

These two case studies illustrate creative solutions to enable people with physical disabilities overcome job task barriers through the use of commercially available products and custom modifications.

ACKNOWLEDGMENTS

The author wishes to thank Jerry Anderson and Ralph Cleaver of the Center for Independent Living of North Florida for fabricating the workstations. I would also like to thank my supervisor, Terry Ward, for introducing me to the rewarding field of Rehabilitation Engineering.

Patti Barrett
Rehabilitation Engineering Technology Team
Department of Labor and Employment Security
Division of Vocational Rehabilitation
325 John Knox Road, Bldg. E, Suite 100
Tallahassee, FL 32399-4119

Jet Skiing for Fun and (Non)-Profit: Adaptations for Recreation and Small Business Development

Caren L. Sax
Interwork Institute, San Diego State University

ABSTRACT

This case study provides an illustration of how customized adaptations can be designed and constructed for increased access to recreational activities and business opportunities. The modifications described in this study were developed through a multidisciplinary "Tech Team" effort, supported by Interwork Institute. The Tech Team approach is consumer-driven, i.e., based on the belief that the individual who requests the adaptation should be an integral part of the team. This request was initiated by a 34-year old man, Shawn, who was interested in jet skiing. After a motorcycle accident left him paralyzed from the chest down, Shawn still wanted to be active in sports, but knew he needed modifications for stability and safety. The initial adaptation designed to stabilize his legs was successful and as a result, Shawn pursued competitive racing and eventually, developed a non-profit business to promote participation in water sports by individuals with physical disabilities.

BACKGROUND

Shawn was injured in 1990 when he was thrown from his motorcycle into a parked car. He broke his back in two places, tore all the ligaments in his right leg, crushed the bones in his left wrist and sustained a serious head wound. He is paralyzed at the T-5 level. During his rehabilitation, Shawn was introduced to riding a personal watercraft, an activity that met his need for continuing an active lifestyle. When he pursued the sport outside of the rehabilitation setting, he found it difficult to rent a jet ski due to liability concerns. Shawn spent most of the following summer riding tandem with friends on a jet ski, but when he tried to ride alone, he lost his balance easily. Shawn found out about Interwork's "Applications of Technology" project when he saw an adapted kayak seat, modified in cooperation with the local aquatic center. He approached Interwork with his ideas for a jet ski modification.

The first step once any referral is submitted for consideration by the project is to pinpoint the targeted activity and ensure that the outcome results in increased participation in one's community. Since Shawn's idea met these criteria, the next step was to complete an assessment on his skills and needs. Typically, a videotape is made of the individual, preferably in the environment where the adaptation will be used. The initial fact-finding video in this case was held at Mission Bay, where Shawn demonstrated the limitations he faced when riding a Kawasaki 750 Runabout™.

OBJECTIVE

The initial objective was to design an adaptation which would enable Shawn to ride a personal watercraft safely. After this objective was met, new goals were set to: 1) improve trunk support in addition to leg support; 2) consider modifications for individuals with more severe physical limitations; and 3) develop a non-profit business to increase access to watercraft through the use of adaptations.

The opportunity for racing and business development grew out of the success of the leg supports. As Shawn built his confidence and skills on the jet ski, he demonstrated that with the right adaptations, people can accomplish feats beyond their expectations. This has occurred repeatedly throughout the "Applications of Technology" project, illustrating that limitations that have been placed on individuals because of their disabilities are arbitrary and typically counterproductive.

THE PROCESS

The process that Interwork has established provides general guidelines for product development, but are flexible according to individual circumstances. The next step for Shawn's adaptation was to begin recruiting a Tech Team, involving people who were familiar with body mechanics, watersports equipment, and materials that would be compatible with the environment. The team can also include interested family members, friends, rehabilitation and education professionals, occupational and physical therapists, and engineers with specific technical skills. A series of steps are followed, leading to an adaptation that is customized according to the individual's needs and priorities.

The videotape was shown to the rehabilitation engineer from Sharp Rehabilitation Services, who was contracted with the University project. Brainstorming continued based on the discussion and demonstration that was recorded on the tape. In addition, a search was conducted to investigate if there were similar adaptations available commercially. Nothing was found so the design process began.

The primary areas of concern were for Shawn to be able to keep his legs close to his trunk and to keep his feet from sliding back in the side tracks of the jet ski. The rehabilitation engineer sketched some possibilities for leg pads which would provide an surface for better leg balance, increasing his stability on the watercraft. Interwork staff began searching for appropriate materials, finding sheets of *Ethafoam* (a non-porous foam) were available in two-inch and three-inch widths. The team, including Shawn, a friend of his, the rehabilitation engineer and Interwork staff, met to figure out a plan of action. Within ten days of the assessment, a prototype was completed. Shawn sat on the jet ski, while the rehabilitation engineer traced an outline of Shawn's upper leg as it was bent in a 45-degree angle, with his lower leg lying almost parallel to the bottom of the craft. The foam was cut with an electric band saw, and the two sheets of three-inch foam were glued together with an adhesive spray. Separate triangular pieces were cut to place behind his feet, preventing them from sliding back. The completed pads fit snugly in the sidetracks of the jet ski, eliminating the need for additional fasteners. The next area of concern was to ensure that pressure on Shawn's knees and shins would be kept to a minimum. After sitting on the craft with the pads in place (on land), Shawn agreed to wear a wet suit to protect his legs until he could have the pads covered.

Shawn field-tested the leg pads on the water that day and was so impressed with his improved performance that he decided to enter a jet ski race scheduled for the following weekend. The pressure on his legs was greater than anticipated, so the rehabilitation engineer added an extra layer of padding with a softer foam. Shawn had the pads upholstered at a motorcycle shop, which matched the seat on the jet ski. They had been previously customized to provide a wider and more secure base, as opposed to the hard plastic seat that comes standard on such a craft. Representatives from Kawasaki™ were also impressed with Shawn's performance and offered to sponsor him for the remainder of the ten-city tour. Shawn competed with all able-bodied riders in the Amateur Runabout™ Division. The extra support and stability that Shawn experienced on the watercraft enabled him to go much faster without the fear of falling off during a sharp turn. But the increased speed also threatened the stability that he could maintain with his upper body, which led to the next adaptation.

The first prototype for the seating modification was made to provide more trunk support. Shawn used a fiberglass patio chair as a base and added foam and padding, connecting it to the existing seat for extra strength. Two senior mechanical engineering students joined the Tech Team and began designing an adjustable seat which would also be detachable. The design for the prototype consisted of three components: position adjustment bracket, seat back and jet ski seat. The bracket was constructed from aluminum plate and bolted with aluminum tubing reaching below the structure of the seat. The seat back was fabricated from a plastic boat chair, reinforced with aluminum for side supports, and was connected with stainless steel pins into the tubing. The pins could be placed into three positions and the back support was removable. Shawn now has three seat designs: a low-back and high-back model, both one-piece designs, and the prototype of a detachable seat, which needs additional modifications.

RESULTS

Beyond the results of becoming a proficient jet skier for recreation and competition, Shawn realized that there were many other people with physical disabilities who might enjoy the sport. He co-founded Aqua Sports Association for the Physically Challenged, a non-profit organization with the mission of bringing awareness to the community regarding the potential of active participation in watersports through the use of customized adaptations. He is beginning to set up instructional courses on the use of personal watercraft and would eventually like to manufacture and market the adaptations. ASAPC also sponsors events for children and adults to try out the adaptive equipment and coordinates efforts with other aquatic sports groups and water safety organizations.

DISCUSSION

The success of each adaptation has led to new ideas. Shawn started with a single idea but has accomplished many in less than two years. The next tasks are to modify the detachable seat with a quick-release handle and to investigate the possibility of modifying the throttle control so that an individual who is quadriplegic can operate a jet ski independently. Also interesting to note is that many of the amateur and professional jet skiers were intrigued with the adaptations, and may want to use them to improve their own performances.

As a final note, it is valuable to emphasize the successful use of the multidisciplinary team approach, which in this case, evolved as the needs changed. During the field-testing stage, many individuals rode the watercraft to offer their comments and suggestions and, as a result, want to participate in the next round of modifications as new members of the team.

ACKNOWLEDGMENTS

U.S. Dept. of Ed. Grant Award #H235C30052
Program Title: Special Projects & Demonstrations
"Applications of Technology: A Community Model"

Special thanks to Shawn Gray & Gail Farwell, ASAPC; Ken Kozole, rehabilitation engineer; Debra Platek & Judy Edwards, mechanical engineering students

Caren Sax
Interwork Institute
San Diego State University
5850 Hardy Avenue, #210
San Diego, CA 92182
Voice: (619) 594-2462
FAX: (619) 594-4208
E-mail: csax@ucsvax.sdsu.edu

A D.I.Y, Low Cost, Two Level Work Station

MICHAEL E. SWORDS
SWORDS AND ASSOCIATES

ABSTRACT:

A first design of a low cost, two-level work station is assembled from off the shelf hardware store items. For wheeled mobility consumers, the tall, the small, all in between, the device provides two adjustable work surfaces. Both surfaces move almost five feet and tilt. This specific application is for a computer work station. Limitations and design improvements are discussed.

BACKGROUND:

For this consumer, prolonged sitting causes lower back strain. As central nervous system stress increases, "dyslexia" and sensory integration difficulties increase. Excessive keyboarding errors become rampant and annoying. These can quickly snowball into frustration and anxiety.

Sensory integration traits and "dyslexia" are lasting neuropsychological conditions. There is no escaping body stiffening from the insidious advance of physical maturity. As midlife continues its relentless march, wrist and hand pain is becoming a significant issue. These can quickly add up to premature fatigue.

IMPLICATIONS:

A two-level computer work station provides changes in position. Fatigue will lessen. Keyboarding rate and accuracy improve, frustration and anxiety diminish. Greater productivity means more time for fun and play. Concentration and attention improve. The risks of cumulative stress syndrome lessen. Increased accuracy and output rate will further enhance self-esteem.

THE PROBLEM:

Commercially available two-level adjustable work stations are plentiful. Only one turned up having enough range to provide the right ergometric positions for a person 6'3" tall. It lacks certain desirable features and cost more than four thousand dollars. Only a home-brew unit can provide the necessary range of movement--at a workable price.

APPROACH:

This design incorporates several criteria; universality, low cost, easy adjustments over a wide range of heights, accommodate loads up to forty pounds (less the weight of each shelf and its parts), made from off-the-shelf retail hardware store items, only basic skills and tools needed for assembly.

DISCUSSIONS:

Construction:

Two variations were considered, free standing and wall mounting. A wall mount is a little simpler to construct, slightly less expensive, and has a smaller footprint. A free standing design needs more floor space, is more challenging to design and build, but is more portable.

Sub-assemblies make up the work station. Two independent floating plywood shelves have locating and locking mechanisms to provide a stable work surface after adjustments. They "float" in a clamping track that adds structural support. Four plastic pipe ducts house counter-weights and pulley systems.

Floating Shelves: The upper and lower shelves are counter-weighted to "float." The action is identical to a sash window. Both are cut from 3/4" plywood. Eye bolts and S-hooks connect the shelves and two fully independent pairs of counter-weights. Stacks of fender washers on threaded metal rod make up the counter weights. Polypropylene rope (3/16") connects the shelves and counter-weights rope. Threading the connecting rope through a pair of dual awning pulleys provides leverage. This four pulley arrangement gives mechanical advantage.

Across the bottom of each shelf is a length of 1/2" black iron pipe. Two standard electrical pipe hangers support it. The ends of this pipe terminate with a coupling. The width of the pipe and couplings is slightly less than the inside separation between the clamping tracks.

A screw and handle end of a Pony Clamp[R] thread onto one end of three inch length of pipe. A 3/4"pipe flange slips over the free end. Next, the pipe passes through the opening in the clamping track. A 1" and a 3/4" washer slip over the free end of short pipe. Screwing the two Pony Clamp ® subassemblies into the couplings completes the shelf clamp. (The coupling substitutes for the tail stock supplied with clamp.)

Turning the handles tightens the screws. This action pinches the big washers and the pipe flanges together on either side of the track. Firmly tightening the screws on both sides locks the shelf in place at the desired height.

For this application, adding the monitor and keyboard makes the shelves loose their balance. Counter weighing restores the balance. Here, 1 1/2" x 3/16" cut steel bar stock, 1" X 12" mending irons do the job. A clamp made from 1/2 PVC pipe and fittings holds the monitor in place. The four outside legs of this clamp terminate with 1/2" slip-thread adapters. These pass through the shelf. From the underside, 1/2" conduit nuts, bearing on 3/4"-1/2" electrical box knock-out reducer washers, secure the clamp and in turn the monitor. To hold the keyboard in place are four L style clamps. These are made from plastic stand-offs, machine screws, two inch mending iron, and rubber furniture tips.

Clamping tracks: Two lengths of slotted metal angle make a U-shaped bearing surface for the clamp assemblies. They distribute the downward load of the shelves and counter-weights. Four inch mending irons join each of the two lengths of slotted angle. A separation between them leaves clearance for the pipe mounted to the underside of each of shelf. This arrangement helps keep the shelf aligned as floats up and down the track.

Plastic pipe ducts: These contain the counter-weights and pulley system. In addition to providing a neater appearance, they provide safety features. They sheath pinch points, inherent in a pulley system. Should one of the ropes break, they contain the free fall of the metal counter-weights. Schedule 40 PVC 1 1/2" pipe lengths and fittings are solvent welded together to form a big, lopsided, U. The upper leg houses the pulley system. The long vertical contains the counter-weights. The lower leg makes a base and provides a surface to anchor the clamping track.

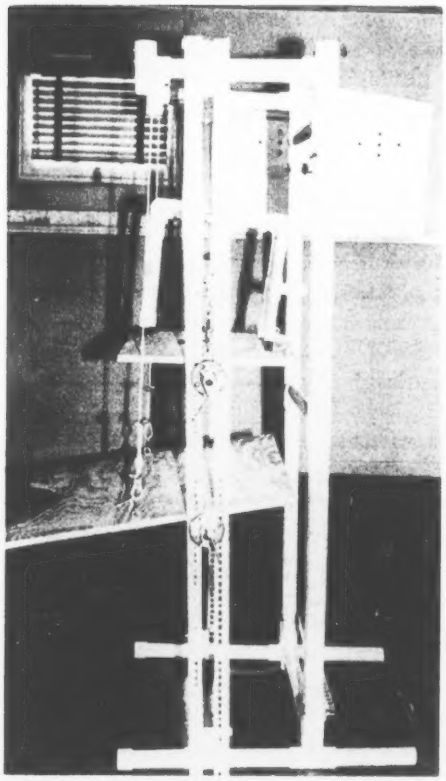
Design Improvements and concerns:
Clamping tracks: The prototype is 80% complete. Despite the counterbalancing, moving the shelves up and down is a bit touchy. If they are not raised evenly, they tend to slant and bind. The tolerances between the clamp assemblies and tracks are too wide. Metal window tracks or garage door tracks and suitable rollers are off the shelf items that may correct this problem. Commercial roller bearing track and rollers may be ideal. The sit stand nature of this application dictated the quick clamp feature. Not needing this feature, a pin clamp mechanism (made from a long bolt) is a simpler and lower cost substitute. It would diminish the slanting problem.

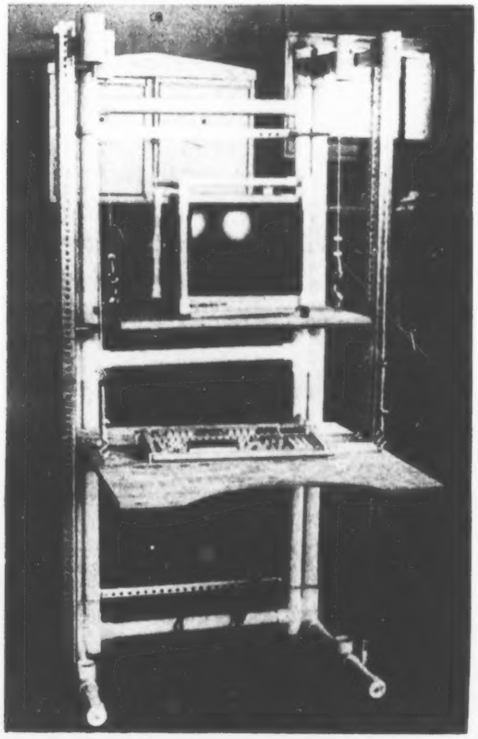
Pulley System: The physically weakest point in this design is the plastic rope. While it can provide years of trouble free service, it does not have the strength of steel chain. The awing pulleys are brass. Metal on metal contact will cause wear. The manufacture specifically advises against the use of wire cable or steel chain with these pulleys. Steel pulleys, of the right size, were not available at local hardware stores. The use of chain on the brass will cause far more wear then rope. Even with the wear, chain would provide a higher measure of security.

Eliminating the original design criterion that all the parts be available at retail hardware stores, this limitation evaporates. Although they were not investigated, surely, commercial grade steel pulleys of the right size are available that avoid this point of concern.

With either the use of chain or rope--as with all moving mechanical devices--regular inspections and meticulous attention to safety is appropriate.

Michael E. Swords
Swords and Associates
5505 Lomond Avenue
Downers Grove, IL 60515
© 1995.





JOB ACCOMMODATION SUCCESSES WITH MATURE INJURED WORKERS: OREGON CASE STUDIES

Mary E. Hoskins and Robert T. Williams
Preferred Worker Program
Oregon Workers' Compensation Division
Salem, OR U.S.A.

ABSTRACT

Historically, injured workers over age 40 have faced exceptional challenges returning to work; traditional re-training has often proved costly and ineffective. One of the unanticipated benefits of Oregon's Preferred Worker Program has been the use of worksite modification monies to successfully return mature workers to their time-of-injury employers. Five long-term success stories are analyzed, showcasing a variety of practical worksite modifications and illustrating some principles of effective job accommodation.

BACKGROUND

All Oregon workers and employers pay a few cents per day into the Reemployment Assistance Reserve, a 110 million dollar fund which provides, among other benefits, up to $25,000.00 to modify worksites to accommodate injured workers' permanent disabilities. This is one part of what is called the "Preferred Worker Program," administered by the Oregon Workers' Compensation Division (WCD).

Together, the authors orchestrated about 1,200 job accommodations between 1991 and 1994. They are directly involved with workers and employers from the time a worksite modification idea is conceived, through development of a proposal and equipment selection, purchasing and installation, and long-term follow-up and "fine-tuning."

The authors offer five case studies of mature injured workers with multiple permanent limitations accommodated by worksite modification, who remained with their employers 12 months or longer after equipment installation. These cases, despite their diversity, illustrate some common traits which seem to characterize successful job accommodations.

OBJECTIVE

To assist others involved in job accommodation, the authors have sought to delineate common features of successful worksite modifications involving mature workers who return to their time-of-injury employers.

METHOD/APPROACH

Closed files from the authors' caseloads were selected using the following criteria: Worker age 40 or over at time of injury, with 12 years or less of formal education; worker returned to work permanently with employer at injury; worker had permanent disability; worker had multiple limitations; one or more onsite contacts had been made with worker and employer; employment could be verified 12 months or more from installation of worksite modification equipment.

- Case #1: 44 year old female teacher's aide with rural school district; upper and lower back strains; permanent restrictions on lifting, twisting, bending and work at floor level. Modifications: Hoyer pool lift; adjustable gurneys; computer workstation; Hoyer patient lift; pool ladder; inflatable vests.

- Case #2: 70 year old male account representative with trailer manufacturer; multiple body parts injured, with complications from arthritis; restrictions on walking, climbing, lifting, carrying, pushing and pulling. Modifications: Duplicate office set-up on ground floor, eliminating stair climbing; three-wheel scooter; handicap operator doors and accessible restroom on ground floor.

- Case #3: 49 year old female custodian in public elementary school; spinal fusion and degenerative arthritis in low back; restrictions on lifting and carrying, pushing and pulling, and twisting and bending. Modifications: Automatic trash dumper/compactor; lightweight folding tables; automatic floor scrubber; chemical proportioning system; desk and file dollies.

- Case #4: 40 year old male painter with city water bureau; disc rupture, low back; restricted from lifting, bending and twisting with loads, decreased range of motion in low back. Modifications: Used truck, fitted with hydraulic hoist and electric hose reel; all-terrain vehicle; scissor lift table; hydraulic elevating cart; "Genie" lift modified with extra rear casters.

- Case #5: 42 year old farm worker on a cattle ranch; amputation of left arm below the elbow; limited dexterity, no lifting of bulky items, no carrying over 25 pounds. Modifications: 1 ton hay baler pulled by tractor; modified front end loader; modified equipment controls.

Results

All of the cases analyzed had certain common features. They suggest chances for successful job accommodation are enhanced when:

1) There is a lengthy, positive relationship between worker and employer;
2) The worker has knowledge, skills and/or abilities which are known to and openly valued by the employer;
3) The injury and resulting permanent limitations are considered valid by the employer;
4) There is continued contact between worker and employer after the injury and before permanent return to work;
5) The modifications do not have a significant negative impact on co-workers in terms of productivity or behavioral change;
6) The worker has the aptitude and is adequately trained to use the worksite modification equipment;
7) Co-workers and immediate supervisors are included in the development and implementation of the worksite modification.

DISCUSSION

These cases suggest certain identifiable factors which may impact the success of modifications from the outset - and about which a third-party expert should gain information. Often, the success or failure of a job accommodation has little to do with the adequacy of the equipment. There are times when worksite modification should be avoided, when "throwing equipment at a problem" is not effective. The authors have suggestions for identifying such cases, based on this analysis and their field experiences. Those predictable factors which CAN be influenced — training, communication issues, equipment selection — should be identified, assigned to specific parties and dealt with.

ACKNOWLEDGMENTS

Funds for the modifications showcased here are provided by the Reemployment Assistance Reserve, a fund established and maintained by the workers and employers of Oregon. The authors wish to thank the Oregon legislature for having the foresight to dedicate monies for restoring injured workers to productivity.

Mary Hoskins
Reemployment Consultant
Preferred Worker Program
Workers' Compensation Division
21 Labor and Industries Building
Salem, OR 97310 U.S.A.
(503) 945-7574
FAX: (503) 945-7581

USE OF JOB ACCOMMODATION BY EMPLOYEES AGING WITH A DISABILITY

Don McNeal, Nancy Somerville, Dorothy Wilson
Rancho Rehabilitation Engineering Program

Abstract

As employees with disabilities age, their needs for job accommodation may change. If these needs are not met, the employee's job may be in jeopardy. This paper describes a study which will investigate the job accommodation needs of employees with disabilities over their work history to determine how their needs have changed and what has been done to meet these needs. Information will be gathered through a questionnaire and structured interviews of 150 individuals who either had polio, have rheumatoid arthritis or had a spinal cord injury.

Background

Functional changes experienced by individuals aging with a disability can make performance of job tasks difficult or impossible and may jeopardize the person's employment status(1,2,3). While the impact of physical declines on employment has been relatively unexplored, it is believed that many of these decreasing abilities can be offset by the provision of appropriate job accommodations, and that these accommodations may prolong employment for workers with disabilities. The right of these workers and others with disabilities to reasonable accommodations are now guaranteed by the Americans with Disabilities Act of 1990(4). It is unclear, however, what problems are being encountered by aging workers and whether these problems are being accommodated.

Objective

This study will focus on workers with a disability and their experiences in getting job accommodations over their employment history. The objectives are to document the changing needs for accommodation as employees with disability age and what is being done to meet these needs. If, as expected, it is found that needs do change, and that adequate accommodation is not being provided, then ideas for promoting and providing accommodation to this population will be generated.

Sample Selection

One hundred and fifty participants will be recruited from a database shared with other research projects within the Rehabilitation Research and Training Center on Aging (RRTC) at Rancho Los Amigos Medical Center (RLAMC). The database is being developed through chart review of RLAMC medical records and a community recruitment campaign. Of the 150 participants, 50 from each of three disability categories - spinal cord injury, post-polio and rheumatoid arthritis - will be recruited. The selection criteria will also include:

- at least 5 years since onset
- worked for at least 5 years
- currently working or unemployed less than 2 years
- at least 40 years of age

Method

Participants will receive a mailed questionnaire that will be used to collect demographic and employment history data. This will be followed with a structured telephone interview that will focus on: 1) functional performance at work and home, 2) work-related problems and accommodations, and 3) knowledge and use of resources. The functional assessment portion will seek information about changes over time and how these changes affected the ability to work and to perform certain personal care tasks. Work related problems will be identified and information obtained about how these problems impacted work performance and how they were solved. The participants will also be asked about their awareness and use of educational, vocational and technical resources.

A worksite visit will subsequently be made for each participant who is currently working to determine if there are accommodations which could resolve any current problems. Written recommendations for solving any current problems will be provided to the participant.

Progress

A consumer advisory committee has been established. Working with this committee, the domains to be investigated were identified and the instruments developed. A pilot test is underway and will be completed by the end of January. A preliminary review of data from seven interviews suggests only minor modification of instruments is needed and so far upholds our belief that these workers have changing needs. It is anticipated that the study will begin in March.

References

1. Maynard, F (1991). The Late Effects of Polio: A model for identification and assessment of preventable secondary disabilities. Final Report for Centers for Disease Control, Cooperative Agreement #U59/CCU503388-03.
2. Meenan, R; Yelin, E; Nevitt, M & Epstein, W (1981). The impact of chronic disease: A sociomedical profile of rheumatoid arthritis. Arthritis and Rheumatism 24(3): 554-549.
3. Krause, James S (1992): Employment After Spinal Cord Injury. Archives of Physical Medicine & Rehabilitation 73 (Feb): 163-9.
4. Americans with Disabilities Act of 1990: Public law 101-336, July 26 1990.

Acknowledgements

Thanks go to our consumer advisory committee who so willingly shared their experiences and contributed their time in helping us develop the instruments. This research is funded by the National Institute on Disability and Rehabilitation Research through grants #H133B30004 to the RRTC on Aging with a Disability and #H133B30029 to the RRTC on Aging with a Spinal Cord Injury.

Address

Don McNeal
Rancho Rehabilitation Engineering Program
503 Bonita St. - Bonita Hall
Downey, CA 90242
(310) 940-7994

VOCATIONAL ROBOTICS: JOB IDENTIFICATION & ANALYSIS

Jill L. Schuyler, Richard M. Mahoney
Applied Science and Engineering Laboratories
University of Delaware and the A.I. duPont Institute, Wilmington, Delaware

ABSTRACT

The results of two preliminary investigations that were performed to better understand the role that robotics may play in vocational rehabilitation are discussed. First, a portion of the Rehabilitation Services Administration's (RSA's) data base consisting of those clients possessing manipulation disabilities was analyzed. The purpose of this analysis was to identify existing trends relating to vocational rehabilitation for the population of individuals for whom a robotic vocational accommodation may be suitable. Second, an analysis of job requirements was carried out using the Dictionary of Occupational Titles and Valpar's System 2000 software. The purpose of this analysis was to identify specific jobs that may be made accessible through a robotic accommodation.

VOCATIONAL ROBOTICS AT ASEL

The Rehabilitation Engineering Research Center on Rehabilitation Robotics at the Applied Science and Engineering Laboratories (ASEL) is actively investigating the application of robotics in vocational accommodations. The purpose of this project is to identify the components that are required to successfully implement a robotic device to assist an individual with a manipulation disability with job tasks. Three areas of concern are being addressed in this work: assessment and training, system integration, and job identification and analysis.

The goal of the assessment and training component is to develop the necessary expertise to assess an individual's ability to interact with a robot, and to train an individual to use the robot to perform job tasks [1]. An Occupational Therapist from a local Easter Seals Rehabilitation Center is being trained at ASEL to program the robot. This work also includes the development of standard tasks, such as object and mail sorting, to assess an individual's ability to interact with the robot. During the second year of this project, a robot workstation will be installed at the Easter Seals Center to begin working more closely with clients.

System integration is concerned with identifying the hardware and software required for a vocational accommodation and integrating them into a single system. A demonstration workstation has been developed for this purpose.

The objective of the job identification and analysis component is to identify jobs that are both appropriate and successful implementations of a vocational robot. The ultimate goal of this project is to stimulate the development of appropriate expertise within established vocational rehabilitation services. This expertise must include job site evaluations appropriate for implementation of robotic systems, knowledge of existing commercial robot technology, knowledge of available user interface approaches and software, and facilities for assessing the aptitude of a potential employee to work with a robot, as well as to carry out training. It is hoped that through this project, the application of robots in vocational settings will grow to be a viable method for enabling the employment of individuals with manipulation disabilities.

RESEARCH QUESTIONS

The work discussed here was performed in response to the following two research questions:

- What jobs are being obtained by individuals with manipulation disabilities?
- What further jobs may be obtained through a robotic vocational accommodation?

JOB ANALYSIS

The RSA maintains a data base of all clients served by the vocational rehabilitation facilities it supports in the 50 states and all US territories. The data base includes 71 different data elements including personal characteristics, such as sex and race, work-related information before and after vocational counseling, and information on what funding sources were utilized and what services were provided.

A portion of the 1991 data base was obtained (this is the last year for which complete statistics were available) for those clients who possess a disability that limits manipulation performance (approximately 120,000 clients out of a total of 605,000). A complete analysis of all elements was carried out and has been compiled in a technical report [2]. It was found that 44% of the clients represented in this portion of the data base were successfully rehabilitated (i.e. obtained employment). The occupations obtained by the clients appear to be generally focused in the service and office sector as can be seen in Figure 1 below. Data elements were often incomplete for those clients who were not successfully rehabilitated. It was, therefore, difficult to determine what factors prevented the remaining 56% of the individuals from becoming employed.

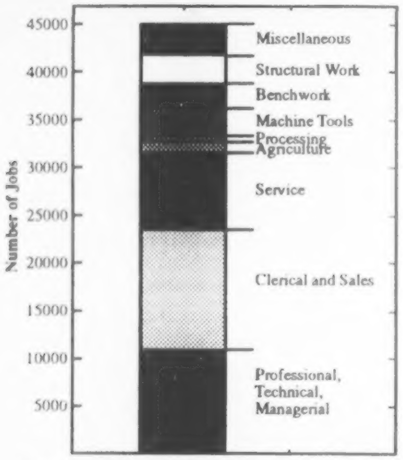


Figure 1: Number of Jobs Obtained by Job Type

The results of this evaluation are limited because they only include the clients of RSA-supported vocational rehabilitation facilities. Many individuals with manipulation disabilities find work on their own or through other vocational rehabilitation services. It is difficult to establish how well the data provided here correlates with the employment status of the entire population of people with manipulation disabilities.

The potential for robotic vocational accommodations to provide a suitable option for some individuals appears to be substantiated by the fact that 56% of the clients were not able to be rehabilitated. It is reasonable to assume that some portion of this group may have benefited from this application of technology. A goal of the vocational robotics program is to integrate robotic accommodations into normal vocational counseling services. Evaluation of the RSA data base has provided an understanding of the services that are provided to clients.

An individual for whom a robotic vocational accommodation is being provided would require a high level of services. Assessment and training would be required to determine the client's ability to interact with the robotic system and to teach the client how to operate such a system. A worksite evaluation would be required that would result in specification of the robotic system. It is expected that the demonstration system under development will cost a minimum of $15,000. It was found that only 5.5% of the rehabilitated clients received services valued at or above this amount.

JOB IDENTIFICATION

Valpar's System 2000 [3] software is being used to identify jobs that may be made accessible through the use of a robotic vocational accommodation. System 2000 cross-references the job title and descriptions from the *Dictionary of Occupational Titles* (DOT) [4] with factors related to job requirements, including education, physical demands, training, and environmental conditions, as specified in the *Revised Handbook for Analyzing Jobs* [5].

The approach utilized in this evaluation was to create several fictitious baseline client profiles that contained scores for physical abilities, in particular, strength, reaching, handling, and fingering, that were representative of someone with a severe manipulation disability. Each of these profiles was paired with a similar profile that reflected an increase in strength of the fictitious client, where an assumption is made that the use of a robot effectively augments an individual's manipulation ability. A search of the DOT was performed for each pair, which resulted in a list of jobs for which the fictitious clients would have been considered suitable. By comparing the results of the search for each pair, it is possible to obtain an indication of those jobs that may be made accessible through a robotic accommodation. Further insight may be gained by performing the search for increasing levels of education. The results of this exercise have been compiled into a technical report [6], a portion of which is discussed in the following paragraphs.

Three different pairs of profiles were analyzed, where A, C, and E are the baseline profiles, and B, D, and F are the improved profiles. Each pair was defined with a particular degree of manipulation ability and possessing either sedentary or light strength. The number of possible jobs was determined for each profile for increasing levels of required education, the results of which are shown in Table 1. The required education levels were defined by schooling level as well as vocational experience of Reasoning, Mathematics, and Language into six general levels[5]. The first profile in each set is characterized by sedentary strength and the second by light strength. As you move down the table, the profiles are characterized by increasing levels of manipulation abilities. For each pair, approximately twice as many jobs were identified for the profile with light strength, as compared to that with sedentary strength.

BEST COPY AVAILABLE

Pair	-->> Increasing Education Level -->>						Total
A-B	0	0	1	3	25	12	41
	0	2	11	15	41	15	84
C-D	0	1	11	55	186	48	301
	3	23	79	288	334	66	793
E-F	25	91	217	316	412	99	1160
	299	1475	1404	1633	860	174	5845

Table 1: Number of Jobs Identified for Each Profile for Increasing Education Level

Figure 2 shows the number and types of jobs identified for profiles C and D, which represent the mid range of manipulation ability for the profile pairs. As the level of required education increases, so do the opportunities in all of the job fields with a large increase in the professional, technical, and managerial fields. The majority of the jobs that were appropriate were professional, technical and managerial, clerical and sales, service, and processing. It is apparent that only a slight increase in manipulation ability results in a substantial increase in the number of jobs for which an individual may be eligible.

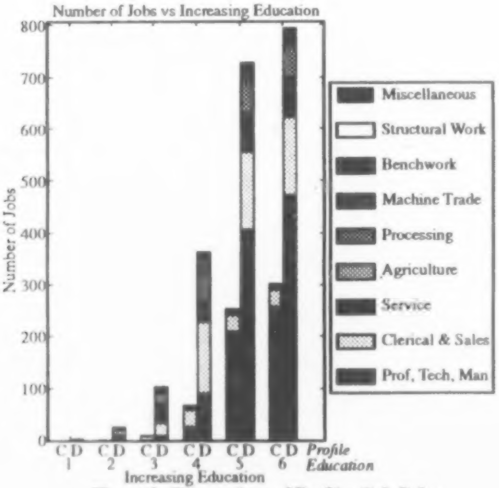


Figure 2: Comparison of Profiles C & D for Increasing Level of Education

DISCUSSION

Several inferences may be drawn by comparing Figures 1 and 2. Figure 1 shows the number of jobs that were actually obtained by individuals with manipulation disabilities within each job category. Figure 2 shows the number of different jobs within each category that theoretically should be accessible to someone with a manipulation disability. The information in Figure 2 is roughly correlated with the results of the RSA data base search, but the proportion of jobs in the three major categories is not as great as that for the job identification search. It appears that further job opportunities may be identified in these categories.

The fact that the distribution of job types is similar for the RSA evaluation and the job identification for profile D indicates that the baseline profile should perhaps be changed to profile D. In this case, comparisons between the searches for profiles E and F with D may reveal more realistic results.

REFERENCES

1. R.G. Gosine, R.M. Mahoney, J. Gatiss, R.D. Jackson, G. Dargie, J. Gibson, D. Scott, T. Jones (1991). Interactive robotics to aid physically disabled people in manufacturing tasks. *Proceedings of the Institution of Mechanical Engineers Part B: Journal of Engineering Manufacture* **205**: 241-245.
2. J.L. Schuyler, R.M. Mahoney (1994) *Employment Trends of People with Physical Disabilities as Determined through Evaluation of the RSA Vocational Rehabilitation Data Base*. Applied Science and Engineering Technical Report Number #ROB9406, A.I. duPont Institute and the University of Delaware, Wilmington, Delaware.
3. *System 2000 Instruction Manual*, Valpar International Corporation, Tuscon, Arizona, 1992.
4. *Dictionary of Occupational Titles*, U.S. Department of Labor Employment and Training Administration, JIST Works, Inc., Indianapolis, 1991.
5. *Revised Handbook for Analyzing Jobs*. U.S. Department of Labor Employment and Training Administration, JIST Works, Inc., Indianapolis, 1991.
6. J.L. Schuyler, R.M. Mahoney (1995) *Job Identification for Robotic Vocational Accommodations*. Applied Science and Engineering Technical Report Number #ROB9501, A.I. duPont Institute and the University of Delaware, Wilmington, Delaware.

ACKNOWLEDGMENTS

This research is supported by Grant Number H129E20006 from the Rehabilitation Service Administration, Grant Number H133E30013-94 from National Institute on Disability Rehabilitation Research (NIDRR) for the Rehabilitation Engineering Research Center on robotics, and the Nemours Research Programs.

Jill Schuyler
Applied Science and Engineering Laboratories
A.I. duPont Institute
1600 Rockland Road, P.O. Box 269
Wilmington, DE 19899 USA
Internet: schuyler@asel.udel.edu

BEST COPY AVAILABLE

WHEELCHAIRS IN CONTROLLED ENVIRONMENTS

Michael N. Kozicki
Forth Research, Inc.
Scottsdale, AZ U.S.A.

ABSTRACT

This paper discusses how wheelchair users may be able to work in certain accessible controlled environments (semiconductor manufacturing facilities, pharmaceutical fill areas, etc.) by using a wheelchair which is cleanroom compatible. Suggestions are given regarding methods of providing wheelchair access in cleanrooms. Also covered are the operational considerations of wheelchairs in controlled environments, including certain critical safety issues. The application of cleanroom wheelchairs in the evacuation of sick or injured workers is also discussed.

INTRODUCTION

The movement of the modern world toward the use of controlled environments in industry, medicine, research and academia has created a rather disturbing problem for a particular group of citizens. Since there are rigid protocols regarding what may be taken into cleanrooms and sterile areas from the outside, it is not practical for a person who is physically challenged to bring their *wheelchair* into the cleanroom to work. This effectively precludes people with physical disabilities from many jobs in the high technology sector. This paper discusses how wheelchair users may be able to work in certain accessible controlled environments by using a wheelchair which is cleanroom compatible. It also covers the application of such wheelchairs in the evacuation of sick or injured workers.

THE CLEANROOM WHEELCHAIR

Today's wheelchairs fall into a number of different categories but they all share the same disadvantages - they are inherently dirty and are difficult to clean. They typically contain some combination of open frame ends and adjustment holes, complex folding mechanisms, and crevices and folds, all of which catch and retain undesirable material. In addition, the frame coatings flake and seat pads shed lint, and the moving parts release metal and plastic particles and lubricants. (It also is obvious that a wheelchair which has just rolled across a muddy parking lot is not the most welcome piece of equipment in the cleanroom!) Cleanroom incompatible wheelchairs mean that only a handful of wheelchair users have made their way into controlled environments to work.

Recently, a cleanroom compatible wheelchair has become available. This compatibility is possible due to the wheelchair's intrinsic cleanliness and cleanability. For example, the frame has a polymer coating, identical to that used in many cleanroom systems, and particle trapping points are minimized by design. Metal-to-metal contact is avoided in all moving parts by the use of self-lubricating polymer bushings and the tires are a durable treadless plastic. The seat and back pads have their own cleanroom "garments"; the user has a garment which may be easily donned, without touching the floor, by someone with limited lower body mobility. The chair also folds in such a way as to take up a minimal amount of space in the changing room (where it resides when not in use) whilst allowing ample underseat room for carrying tools, materials or accessories. Finally, debris is removed from the tires by the use of wheel cleaners and static is dissipated by a discharge wheel.

REASONABLE ACCOMMODATION

Of course, the cleanroom wheelchair only offers accessibility to a cleanroom which is already accessible. The work spaces have to be wide enough and the work surfaces, controls, or displays low enough for a wheelchair user. In addition, all physical barriers would have to be removed to allow the chair to roll unimpeded through the room.

The problem for most employers is the question of what exactly is "reasonable" accommodation? To give a specific answer to this question, let us consider the case of a paraplegic worker in a controlled environment. The first barrier is the changing room, an area which is frequently rather cramped. The cleanroom wheelchair would be stored here, folded and hung on the wall so as not to take up precious space (the same chair hanger could be used to store the employee's wheelchair after transfer). When the worker's own wheelchair and the cleanroom wheelchair are on the floor during the transfer, the passage of other workers may be impeded. This means that the disabled employee may have to enter the room before or after the shift change - a relatively simple alteration of work schedule. Many cleanrooms have an airshower between the changing room and the cleanroom proper. Many are at floor level and are large enough to take a wheelchair but some have a step and are more telephone booth-like. This latter type obviously causes problems for wheelchair users. If the shower is large enough to take the chair, a ramp in and out may be all that is required, if not, a larger airshower will have to be constructed. This can be a major task and could constitute considerable disruption.

In the cleanroom, the problems shift to the work spaces. Most equipment in controlled environments has not been designed with disabled workers in mind and therefore the work areas may have to be modified. The most accommodating work spaces are simple benches as used in assembly, inspection, and testing operations. Workers will tend to be seated at these benches in any case and therefore wheelchair integration becomes a matter of ensuring that the benches and chairs are adjusted to the correct relative heights and that materials, tools and controls are within easy reach without stretching or overbalancing. This is simply workspace ergonomics; the same analyses and modifications should be performed for any worker. At the other end of the equipment spectrum are the most advanced processing systems, (for example, those used in the semiconductor industry). Many of these have controls which are remote from the system itself and therefore may be placed at a level suitable for both seated and standing employees. The main problem in the cleanroom is the equipment which does not have remote control panel capability, has high and unadjustable work surfaces, or has displays or microscopes well above work height. In these cases, it may be possible to provide a raised floor section with ramps to bring the wheelchair to the correct level. The main problem with this approach is that it puts a standing employee using the same equipment too high to use it comfortably. Perhaps the best solution to this problem is to provide an elevator as part of the cleanroom wheelchair. In this way, the occupant could be raised to a suitable height without the need for ramps and platforms. Such elevator systems are currently being made available.

The above examples show that the provision of reasonable accommodation is a thorny problem but is not out of the question in controlled environments. There will, of course, be areas in cleanrooms which will never be wheelchair accessible at reasonable cost and effort. For example, some existing cleanrooms have extremely narrow aisles between equipment. This cuts down wheelchair maneuverability. These work spaces cannot be easily modified. However, the good news is that many new facilities are being designed and built with wheelchair access in mind, making the process of reasonable accommodation so much easier from the start.

OPERATIONAL CONSIDERATIONS

In considering the operational aspects of a wheelchair-using cleanroom employee, the two biggest questions relate to microcontamination and safety. Taking the example of a paraplegic employee once more, there may actually be an advantage to moving around a cleanroom in a wheeled conveyance. As long as the wheelchair is well designed with low contamination bearings, non-shedding coatings, and tires which can withstand perforated floors, the unit itself will generate little in the way of airborne contamination. The main generator is the employee and the release mainly depends on two factors - apparel material/type and wearer activity. The wheelchair occupant will wear a suit of the same material as other cleanroom employees, different in design to allow easy donning but no less occlusive. However, for the paraplegic wheelchair user, activity during travel is limited to the upper body. Upper body motion has been shown to produce considerably less contamination than that produced by a walking person. Hence an employee in a wheelchair could actually be cleaner than a walking worker!

The question "how safe is a cleanroom worker in a wheelchair?" is more difficult to answer. A seated person would be more prone to injury from chemical spills as liquids would not drain off the upper legs and lap very easily. However, an oversized chemically-resistant apron would provide excellent protection to any seated person. The apron would have to cover the whole body, including the feet, and the wheelchair. A shaped hard shield which attaches to the chair may also be used for protection against spills and splashes. It is also possible for a wheelchair to pass through a chemical puddle with reasonable safety. Tire shields or "fenders" which prevent the user's sleeves from touching the tires and becoming contaminated would also ensure that the user will not come in contact with the wet tires. Unfortunately, there are other risks related to wet chemical equipment. Since most wet benches are designed for use by standing individuals, the opening for the hands is near face level for a person in a wheelchair. Obviously, a worker in a wheelchair could not work at one of these benches as safely as a standing operator unless a seat elevator was used or substantial modifications made to the work area.

The remaining perceived safety problem is one of emergency evacuation. Assuming that the exit routes are wheelchair accessible, will a person in a wheelchair still be able to escape along with the other employees, or will they be left behind or tend to slow the evacuation process down? Many paraplegics can move with great speed in their chairs and are unlikely to hinder any evacuation, but what about those who are a bit slower due to reduced upper body strength? Are they to rely on others to push them to safety? This latter point is probably the most controversial of all the points we have discussed so far. First of all, a fire in an office building can be every bit as threatening as a fire in a cleanroom and yet we do not ban wheelchair users from offices on the grounds of evacuation hazards. In addition, if we are so concerned about the ability of our employees to escape a threat, perhaps we should first look at non-disabled workers, particularly those who are overweight, those who are heavy smokers, and so on. Can the less-than-fit escape with the others? We have allowed these people to work in cleanrooms since the beginning, so the safety argument against disabled workers weakens somewhat. There is a legitimate concern regarding the blocking of wheelchair escape routes by debris. If this is a concern, it will be necessary to provide extra exits, crash panels, or even "areas of refuge" within the cleanroom.

WHO USES A CLEANROOM WHEELCHAIR?

A very obvious argument against the requirement for a controlled environment wheelchair is that many companies do not believe that they have anyone who needs such an item. It is true that industries which use controlled environments are not exactly overflowing with people with physical disabilities. However, until recently, there was neither the strong incentive nor the means to employ physically challenged workers in cleanrooms. It is estimated that there are currently some 180,000 post-secondary students who utilize wheelchairs and are preparing for entry into the workforce. How many will end up in high-technology jobs will directly depend on how willing these companies are to accept the controlled environment wheelchair concept.

Even if we do not consider the new workforce element, there are two very strong arguments for the widespread introduction of wheelchairs into controlled environments. The first relates to the fact that current key employees could find themselves, through accident or sickness, as temporary or permanent wheelchair users. Reassignment or retraining may not be options due to indispensability, cost, or the wishes of the individual. The inevitable counter-argument is that "we will cross that bridge when we come to it". However, this is where argument two comes in - what if your employee is injured or suddenly takes ill inside the cleanroom? If this happens anywhere else in the plant, a standard wheelchair is available to take them for treatment. If a permanent cleanroom wheelchair is not available, the only options are to use the standard wheelchair (and shut down all operations for some time while doing so) or to drag the person out by the heels! The industry is full of anecdotes relating to such incidents. Judging by these horror stories, the cleanroom wheelchair is long overdue.

CONCLUSIONS

Many of the jobs in controlled environments could quite easily be performed by a physically disabled person. For example, inspection, assembly, testing, equipment loading, equipment operation from a control panel, programming and a wide range of other technical, scientific and managerial jobs could all be carried out from a wheelchair. The advent of the controlled environment wheelchair and the move toward designing new facilities with access in mind have made the integration of disabled employees technically feasible. This has been taken very seriously by several large US corporations who are either studying the possibilities or actually using wheelchairs in their cleanrooms. Even though the industry is not currently overflowing with physically challenged employees, the concept of having a cleanroom-compatible wheelchair on-hand to evacuate sick or injured workers will most probably promote the widespread availability of such systems.

Dr. Michael N. Kozicki
Chairman
Forth Research, Inc.
1435 N. Hayden Road
Scottsdale, AZ 85257 U.S.A.
(602)423-2998

AN ENVIRONMENTAL CONTROL SYSTEM
FOR A SEVERELY DISABLED PERSON WORKING AT HOME

Dominic P.K. Cheng
Rehabilitation Engineering Centre
Hong Kong Polytechnic University, Hong Kong

ABSTRACT

For the severely disabled working at home, there is often a need for assistive devices to control equipment for work and equipment for entertainment in an integrated manner. This paper describes development of an environmental control system to enable a totally flaccid young man suffering from muscular dystrophy to run a small tour-bus operation in the comfort of his own home.

BACKGROUND

In the late 1980's, an occupational therapist approached our centre to explore the possibility of using an assistive device to enable a bright young man suffering from muscular dystrophy to drive an electric wheelchair. He has excellent speech but was totally flaccid. However he can move one big toe consistently without socks on. A single switch wheelchair interface with a semi-latched mode (1) and a special toe-switch was designed for him. The wheelchair interface was an instant success but since his toe would easily get out of position whenever the wheelchair was used outdoors, or bumped into something, the toe-switch was replaced with a blow switch. However, the toe-switch was found to be ideal for him at home where there was no chance of dislocation. He used the toe-switch to control a Scanning Keyboard which was custom designed for him by a volunteer. This Scanning Keyboard was an alternative input device for an XT-compatible PC as well as a scanning control for three pulse-dial telephones and the microphone of a high-frequency transceiver. The young man used these telecommunication devices to run a small tour-bus business. This configuration is shown as a block diagram in Fig. 1

STATEMENT OF THE PROBLEM

There are mainly two problems. The first problem is common to the severely disabled at home while the second is due to this young man's particular requirement for telecommunication equipment to run his business.

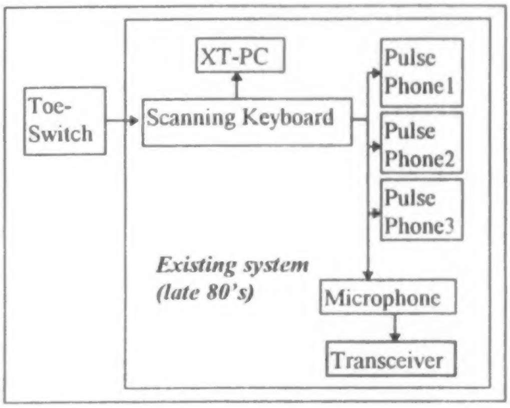


Fig. 1 Existing system in the late 80's

Problem 1

The young man relies on his grandmother and visits from paramedics and volunteers for his daily needs. He wants to be able to let these callers in. Getting outside help in case of an accident at home has been of concern.. Running a tour-bus operation is a full-day and evening job. His main entertainment is to enjoy live and recorded audio/visual material and he wishes to have direct control of his A/V equipment.

Problem 2

In the early 90's, he found that without the use of a touch tone telephone, services from the telephone company required to run his operation will not be possible. In addition, one of the control channels for the pulse-dial telephones failed and he could only control two telephones. The volunteer who designed the system was no longer available to either maintain or upgrade the system. The young man wanted access to touch-tone technology and he approached the author in July 1994 for a solution.

RATIONALE

In the late 80's , the young man's telecommunication needs were well satisfied with his existing system as shown in Fig. 1. The main concern was to design a system to work with his existing system to satisfy requirements as stated in Problem 1.

In July 1994, the main concern was to replace his telecommunication equipment in such a way that the old system could be put back to work fast and easy in case the new system failed. This is very important because he needs the equipment to run his business.

Implementation was done with low cost in mind because the user has to bear the cost of the equipment. This is in harmony with the idea of not to replace something that has been working well.

DESIGN AND DEVELOPMENT

The environmental control system implemented to solve the user's problems in the late 80's is shown in Fig. 2. Two of the three scanning environmental control modules developed in this centre were used together with the user's existing Scanning Keyboard which controlled the telecommunication equipment. We worked together with the volunteer who designed that system so that control from the single toe-switch could be passed back and forth between our ECS modules and his Scanning Keyboard.

The Master Unit has been designed for a single-switch user to control appliance on/off. The intercom and electric door-lock enables the user to let people in after checking their identities first. The electric door lock will be automatically activated if the alarm function is selected by the user. The alarm is mounted outside the door of the user's flat and the neighbours are informed of this device and follow up actions. The Trainable A/V Interface enables the user to control up to 7 devices with up to 15 controls codes each. (2)

In case of a failure of the ECS system, the pulse-dial system can be put back into action by connecting the toe-switch to the Scanning Keyboard and reconnecting the telephone lines.

In July 1994, the Telephone Interface developed in this centre, which controls a touch-tone speaker-phone with numeric display, were modified to control a commercial 2-line touch-tone speakerphone with the usual added features of multi-line telephones such as Hold and Conference. The Telephone Interface was installed in August 1994. The present configuration is as shown in Fig. 3. With this implementation, the user can take advantage of services offered to users with touch-tone phones, such as redirecting his third telephone line to his 2-Line speaker-phone.

In case of failure of the Telephone Interface, the former pulse-dial system can be reconnected by a) removing the cable between the Master Unit and the Telephone Interface, b) removing the telephone lines from the 2-Line speaker phone and re-connecting them to the pulse-dial system, and c) re-installing the control cable from the Master Unit to the Scanning Interface.

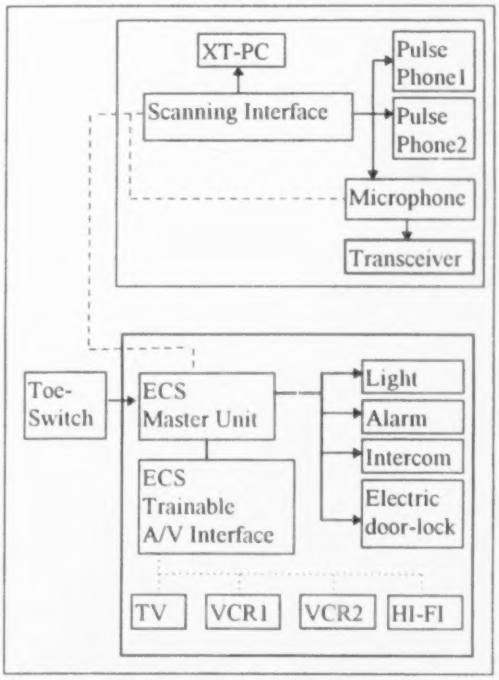


Fig. 2 ECS implemented in the late 1980's

EVALUATION

When the ECS was implemented in late 80's, the user found the scanning speed too slow after a couple of days. Scanning speed was increased accordingly. There are nine scanning speeds but an attendant has to select it for the user. There has been no failure of the ECS up to this point.

562

The Telephone Interface locked up once after the first couple of weeks of use for unknown reasons. It was reset by powering down and has been working properly up to this point.

The user is generally happy with the system because it does exactly and reliably what he has in mind.

DISCUSSION

The user had been fully involved in the implementation of the system and this ensures the system performs as expected. Using a PC-based system was considered but rejected for the following reasons:

In the late 80's, PCs were both expensive and not very reliable. A single PC monitor calls for frequent switching of graphic screens for different control functions sets and this will slow down the user's response to incoming calls.

From both financial and practical viewpoints, it is unwise to discard something which has been working well and meets the user's needs.

In 1994, PCs are more reliable and the Windows environment is very suitable for displaying graphics. However, the development and hardware costs are high and we agree that there is no advantage over the present implementation.

REFERENCES

1. Cheng P.K. (1989) Semi-latched mode single switch wheelchair interface. RESNA 12th Ann. Conf. 11-12.
2. Cheng P.K. (1989) A scanning programmable remote control, RESNA 12th Ann. Conf. 87-88

ACKNOWLEDGEMENTS

This work was supported by the Royal Hong Kong Jockey Club.

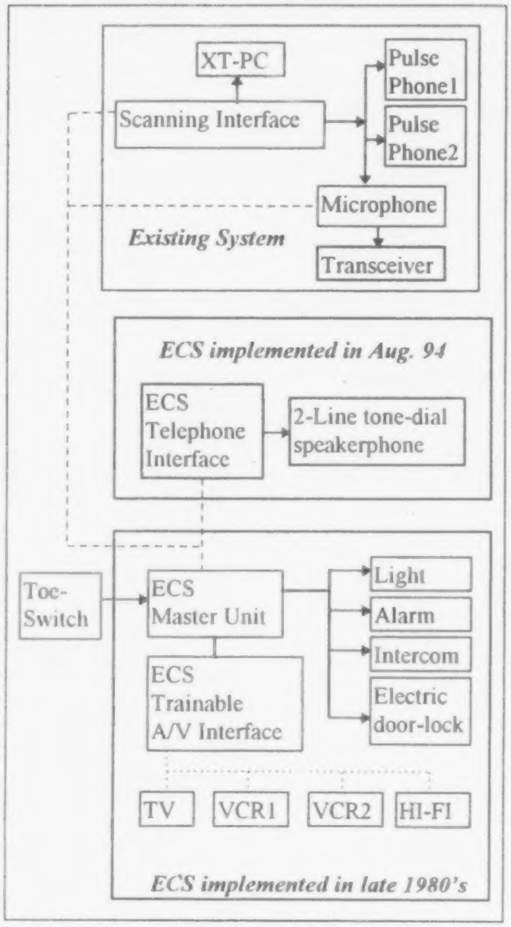


Fig 3 ECS system as of August 1994

Dominic P.K. Cheng
REC
Hong Kong Polytechnic Univ.
Hung Hom, Kln.
Hong Kong
Office: (852)2766-7669
Fax: (852)2362-4365
Email: RCDPKC@HKPUCC.PolyU.EDU.HK

SIMPLIFICATION OF ESSENTIAL FUNCTIONS USING DESIGN FOR ASSEMBLY TECHNIQUES

Robert F. Erlandson, Ph.D.
Wayne State University

Judith A. Phelps, OTR
Wayne County Regional Educational
Service Agency

Abstract

The ability to do the essential functions of a job, unaided or with reasonable accommodations, is a key issue with respect to competitive employment. Typically, essential functions involve working at specified assembly rates, production rates, or acceptable error rates. Reasonable accommodations are usually one-of-a-kind, designed to enable an individual to perform the task.

This paper reports on a pilot study involving workers with disabilities and the simplification of the essential components of a job. Design for Assembly (DFA) and Design for Manufacturing (DFM) are strategies developed by industry to make business more competitive and cost-effective in today's world market economy. Using these procedures, businesses decrease the number of parts, fasteners or steps involved in assembly or manufacturing. These design procedures were not developed to create options for individuals with disabilities. This study is the first examination of the impact of these business strategies on a disabled individual's ability to perform essential components of a job.

Background

Product Design for Assembly by Boothroyd and Dewhurst (1991) is the current business and industry standard regarding Design for Assemble (DFA) procedures. Their text presents a case study of a pneumatic piston sub-assembly. This piston assembly serves as the example case study for presentation of their "design for manual assembly" methodology. The original design is analyzed and recommendations are presented for a redesign. The redesign is then presented and analyzed. This product was also used in the pilot study cases discussed in this paper. It is well known within the DFA community and serves as a defacto standard of comparison between able bodied workers and individuals with severe disabilities.

Figure 1 shows a breakout representation of the original piston design. The following brief description of the design for manual assembly procedure is based on Boothroyd and Dewhurst (1991). The first step in the procedure is to assign an identification number to each part of the assembly. A worksheet is associated with the design analysis. The parts are all listed in order of assembly. There are nine columns, column 1 being the part's ID number. The remaining eight columns represent design features to be analyzed. For each design a manual design efficiency (EM) score is calculated. The EM score is derived from the eight column design features.

To score the assembly, the device is re-assembled starting with the highest ID number. The remaining parts are added one-by-one. The Product Design for Assembly manual contains numerous charts which codify manual handling operations and manual insertion operations. These data were arrived at by a series of R&D projects and represent normative data for non-handicapped workers. Also provided are charts which relate these operations to minimal handling and insertion times for these operations; again empirically derived data, from non-handicapped workers, for normative values. The original assembly has a manual assembly design efficiency of .29 or 29 percent.

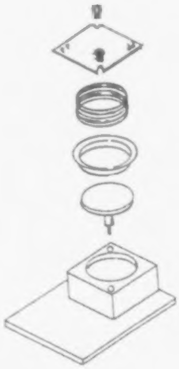


Figure 1.

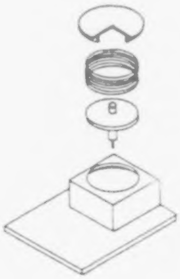


Figure 2.

Figure 2 shows the re-designed device. The re-design has a manual assembly design efficiency of 0.90 or 90 percent. Note that the screws have been replaced by snaps and the piston stop and cover have been combined into one snap-on part. The number of parts was reduced from 7 to 4. The total manual assembly time (TM), based on non-handicapped worker performance, went from 40.75 seconds to 13.29 seconds, a decrease of 207 percent.

An important point for this discussion is that one need not be an engineer to perform the analysis.

With modest training one can become familiar enough with the process to analyze the relatively simple assemblies applicable for the severely disabled target populations.

Research Question

Will the application of DFA techniques improve the assembly rate and task performance of individuals with severe cognitive disabilities.

Method

The Design for Assembly group at Ford Motor Company provided 14 pneumatic piston sub-assemblies, seven with the original design and seven with the new design. Data was collected for training and assembly performance for first the original design and then the re-design. The original design was termed the "Old" design and the re-design was termed the "New" design. Data on the time-to-assemble and notes on training and problem areas were collected for first the Old design assembly and then the New design assembly.

Two sites were used for the pilot study; Services To Enhance Human Potential (STEP) and Riley School. STEP is a private, not-for-profit, community vocational rehabilitation organization. There were seven workers from STEP, each performing 10 assemblies with the Old design followed by 10 assemblies of the New design. The subjects at STEP ranged in age from 32 to 44 and had IQ scores ranging from 28 to 57.

The other site was Riley School, operated by the Wayne County Regional Educational Service Agency. Riley School draws students from 17 local districts and has programs for students with severe cognitive and physical impairments. Four students served as subjects. They ranged in age from 15-17 years old with IQ scores in the range of 10 to 30.

Results and Discussion

Figure 3 summarizes the resultant data. Two bars are shown for each group/design. The left, vertically stripped, bar represents the average assembly time for the group and a particular design. The right, solid, bar represents the normative assembly times for non-handicapped workers, 40.75 seconds for the Old design and 13.29 seconds for the New design.

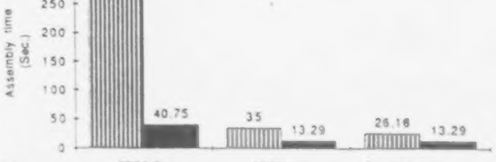


Figure 3.

Figure 3 shows the average of assembly times for all STEP workers dropped from 364 seconds for the Old design to 35 seconds for the New design. This is a statistically significant difference. The observational notes by STEP staff indicated that most of the workers required substantial help in assembling the Old design. Assembly times greater than 6 minutes (360 seconds) really meant that the worker could not assemble the part without assistance from staff. Note that the average assembly time, 364 sec. exceeded 360 sec., indicating that on the average the STEP workers could not successfully complete the assembly without assistance, i.e., they could not perform the assembly with the Old design.

With reference to Figure 1, note that insertion of the piston was problematic, it tended to go in at an angle and stick. When this happened worker assembly time suffered considerably in that the workers became frustrated if initial pulling and shaking of the piston did not realign the piston. Holding the cover and trying to screw in the two screws were the major problems. These observations are consistent with the B&D intermediate assembly time values for the piston (5.50 sec.) and the cover (8.86 sec.) and screws (16.6 sec.) for the Old design analysis worksheet. Since these intermediate assembly time values are relatively high, it indicates that everyone slows down at these points. The target population slows down to a much greater degree.

Staff at STEP indicated that the workers seemed to learn the assembly operations, but trouble with the physical demands of the assembly, as noted, clouded the training issue for the Old design. For the New design, staff typically provided only one or two demonstrations of the assembly sequence before the workers understood the process. The problematic assembly steps were removed in that the New piston design has a "handle" to help align the piston upon insertion. This new design has an intermediate assembly time of 3 sec. (as compared to 5.5 sec.). The piston still occasionally misaligned, but at a much reduced rate. The cover and piston stop were combined into one piece which has tabs for insertion and securing, hence removing the need for screws. Since the problematic steps were removed, there was a dramatic improvement in worker performance.

The second group of assemblers was from Riley School and represented individuals with more severe cognitive impairments than the STEP population. None of the workers in this group could complete an assembly of the Old design. The problems with the piston insertion, cover and screws were overwhelming for this group of individuals. All the Riley School workers could perform the assembly task with the New design. Figure 3 shows that the average assembly time for all the Riley workers was 26.16 sec.

Staff attempted five assembly trials for both the Old and New. These followed a training period. Students never mastered the assembly process with the Old design. Some of the students knew what to do, but were simply unable to physically manage the task. With the New design only one or two demonstrations were required before the five assembly trials.

Figure 3 also allows a comparison between the average assembly times for the STEP and Riley School workers. The Riley School workers are more physically and cognitively compromised than the STEP workers. For the New design, from a statistical point-of-view, the analysis results indicated that there was no significant difference between the STEP and Riley School workers. This is significant if it can stand up over a larger sample. It suggests that the re-design principles "leveled the playing field" between STEP and Riley workers, i.e., between groups of workers with very different ability levels as measured by their IQ scores.

Previous work with able bodied workers has demonstrated that the New design increases everyone's assembly time. This data clearly demonstrates that the New design enabled a dramatic improvement in assembly times for all the pilot study subjects as well.

Figure 4 illustrates this phenomena from a total assemblies perspective.

	Could not do assembly	Could perform the assembly		
		Below normative	Between normative and normative + 15%	Above normative + 15%
OLD	47	42	0	0
NEW	0	72	13	4

Figure 4.

Industry DFA experts typically vary the BDI total manual assembly time by plus or minus 15% to account for potential differences between the research determined values and actual assembly values. There were no assemblies of the Old design within the normative to normative plus 15% range and none above the normative plus 15% value.

For the new design there is a dramatic shift in the number of cases in each category. Most striking - there were no unsuccessful assemblies. All the subjects could now perform the assembly task. Next, the number of successful assemblies, but below normative values increased to 72. Note that there were 13 assemblies in the normative/normative +15% range and 4 assemblies above this range.

Figure 4 demonstrates that with Old design none of the target population could do this assembly job. With the New design everyone of the target population could do the assembly job. The re-design created new job opportunities! For the Old design none of the target population could perform in the normative to above normative range. With the New design there were 17 assemblies in these ranges.

The fact that these design approaches might simultaneously do both - be cost/effective for businesses and be reasonable job accommodations for individuals with disabilities is just beginning to be recognized. The product redesign in this study enabled workers to perform the essential functions of a job at near normative rates, with a better quality, streamlined lower cost product for the business.

References

Boothroyd, G., & Dewhurst, P. (1991). Product design for assembly (3rd ed.). Wakefield, RI: Boothroyd Dewhurst, Inc.

Acknowledgments

The authors wish to thank Ann Marie O'Connell, Ford Transmission & Chassis for providing the piston sub-assemblies, Irva Banjo, STEP Staff, and Riley Occupational Therapists Kleah Jacques and Roberta Casterwiler for conducting the field studies, and Glenn Jimmerson, Ford Motor Company, Michael Nobliett, General Motors, and Greg Turner, WC RESA ADAMLAB for their ongoing support of these research activities.

Robert F. Erlandson
Wayne State University
Electrical and Computer Engineering
5050 Anthony Wayne Drive
Detroit, MI 48202
(313) 577-3900
rerlands@ece.eng.wayne.edu

SIG-15
Information Networking

A COMPREHENSIVE SPORTS AND RECREATION PROGRAM FOR ADULTS AND CHILDREN WITH DISABILITIES

Darlene G. Miller, Laura C. Farrell and David Clift
Vermont Adaptive Ski and Sports
Brownsville, Vermont U.S.A.

ABSTRACT

Vermont Adaptive Ski and Sports (VASS) is the most comprehensive sports and recreation program for adults and children with disabilities in the Northeastern United States. Since its inception in 1987, VASS has offered a rare opportunity to any person with a disability to participate in healthy, outdoor sports with family and friends. Besides hosting the largest adaptive downhill ski program in the east, VASS offers adaptive programs in horseback riding, canoeing, dog sledding, waterskiing, camping, and each summer sponsors two aquatics camps for teenagers with disabilities. The organization serves over 1000 people annually with a large percentage of the participants coming from school groups, rehabilitation facilities, and group homes. VASS programs help to integrate person with disabilities from all over the Northeast into the mainstream of society.

BACKGROUND

Individuals with disabilities are often not afforded equal opportunity to engage in recreational activities. This is often due to lack of resources in a community, public attitudes towards persons with disabilities, and/or lack of accessibility. Juxtaposed against this is the recognized value of sports and recreation activities for persons with disabilities. Recreational activities offer a unique opportunity to enhance socialization, communication, and motor development skills for those who participate (1,2). Being disabled does not have to include the word "never" when it comes to participating in sports and recreation.

The idea for VASS grew out of an experience Founding Director Laura Farrell had in 1985 while working as a ski instructor. Ms. Farrell was approached by a family who had a child with Down's Syndrome. This family wanted the entire family to learn to ski together. Inspired by her success with the family and her enlightened awareness of the need for special ski instructors for person with disabilities, Ms. Farrell founded VASS in 1987. Originally called the Vermont Handicapped Ski Foundation, the organization started with two paid staff members and 25 volunteers. Volunteers were trained in the American Teaching Method and learned specialized skills and the use of adaptive equipment. In its first year, VASS served 240 participants, providing them with 550 ski lessons. And in the first year, the annual "Go-For-It" ski camp for teenagers with disabilities made its debut. Five years and 4800 ski lessons later, VASS has expanded into a comprehensive sports and recreation program for adults and children with disabilities.

OBJECTIVE

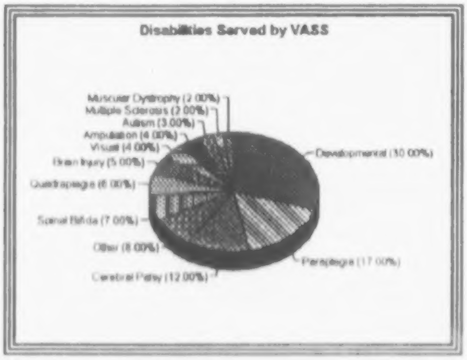
Since the inception of the program in 1987, VASS has experienced substantial growth, evolving from a winter ski program to a year-round, full time program offering many different recreational opportunities to program participants. Striving to promote independence in recreation, VASS works toward this goal with each individual. The organization encourages friends and family members to take part in the learning experience, so that all are educated in the use of adaptive equipment and aware of any assistance that may be required. On a limited basis, VASS has provided a rental program to its participants. This has been a natural outgrowth of the organization's mission as students move from the learning environment to a more recreational environment.

While recreation is the focus of all VASS programs, there are many inherently therapeutic benefits for our participants. VASS encourages independence, self-confidence, and self-esteem by providing a fun and exciting experience geared toward each participant's individual goals and expectations. Each program exemplifies VASS's motto, "If I can do this, I can do anything."

APPROACH

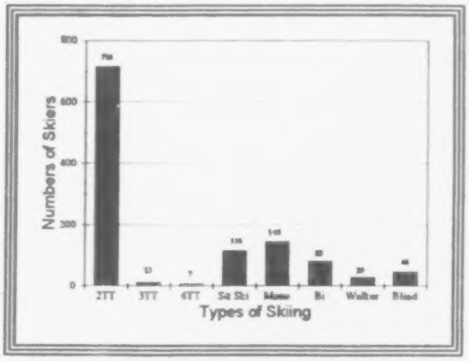
Just as anyone learning a new skill needs to be taught, children and adults with disabilities participating in sports activities for the first time need instruction (1). All VASS programs are staffed by volunteers who provide both basic and advanced instruction in a fun and safe environment. Volunteers participate in adaptive instructor clinics and many volunteers travel to Professional Ski Instructors of America clinics.

VASS programs are not exclusive. Anyone with a disability who wishes to learn to ski, horseback ride, canoe, waterski, play tennis, or camp is welcome to participate in VASS lessons and events. The organization offers many recreation programs throughout the year as well as many competitive sporting events, such as downhill ski racing in the winter.



Adaptive Downhill Skiing

Ski lessons still comprise the cornerstone of VASS. In 1987, VASS volunteers taught 500 lessons at Mt. Ascutney in Vermont. By the 1993-94 ski season, that number had almost tripled to 1484 with lessons offered at Mt. Ascutney, Sugarbush, Suicide Six, and Okemo Mountain. VASS offers lessons in 2-track skiing, 3-track skiing, 4-track skiing, sit skiing, mono-skiing, bi-skiing, walker skiing, and blind skiing. Over 50% of the lessons are 2-track lessons to children and young adults who are developmentally disabled or learning disabled. Yearly, the program hosts a "Go-For-It" day camp for school-aged skiers with any type of disability.



Adaptive Horseback Riding

During the summer of 1994, 50 riders participated in the VASS riding program. With a lot of work, each student gained more and more confidence. Many participated to "try it out", others participated to have fun, and others participated because their doctors prescribed it as appropriate therapy. Six enthusiastic campers also participated in the New Horizons Day Camp for a week of cleaning tack, cleaning stalls, and horseback riding.

Adaptive Water Sports

Summer water sports become more popular each year. In 1989, the Echo Lake Aquatic Camp started with six campers and the motto, "fun in the sun." By 1994, 13 campers, ages 10-16, all with significant disabilities, enjoyed the challenges of an active aquatic program. Activities included tubing, knee-boarding, adaptive water skiing, canoeing, sailing, swimming, scuba-diving, and kayaking.

As part of the growing water program, in 1994, volunteers taught 72 lessons in canoeing, hosted a canoeing and camping trip, and taught twelve individuals to water ski. And for the first time VASS offered summer programming for a group, the Lake Grove School from New York. Twelve students who are deaf or have significant learning disabilities participated in canoe training, hiking, mountain biking, horseback riding, and fishing.

Special Olympics

Each winter VASS hosts Special Olympics ski training. Practices are held every Sunday and the group travels yearly to the Vermont Games.

Ski Racing

VASS hosts numerous adaptive ski racing events including slalom and giant slalom races as well as a United States Association of Blind Athletes Race Camp.

DISCUSSION

Each year, VASS works to provide new programs through which individuals with disabilities can challenge personal limits and set new goals in both recreational and competitive settings. People from throughout the Northeast and Canada travel to

BEST COPY AVAILABLE

569

Vermont to participate in VASS activities. Primarily, participants reside in Vermont, New Hampshire, Connecticut, Massachusetts, Rhode Island, New Jersey, New York, Pennsylvania, and Maine. And VASS programs are often integrated into schools and hospital based programs, providing recreational and therapeutic benefits to all ages.

Providing sports and recreation opportunities for persons with disabilities at an affordable cost can be a tall order. However, like any non-profit organization, VASS exists because of financial supporters, program fees, special events and the generosity of its volunteers. All lessons are staffed by volunteers who provide instruction and support. Sixty percent of all volunteers who started with the program in 1987 still volunteer to this day. Each volunteer is provided both basic and advanced training by the organization. Currently, the program has over 150 volunteers who teach lessons, repair and maintain equipment, and participate in fund-raising activities.

Programs are funded through annual campaigns, special events, and fundraisers. While the largest fundraiser is the Vermont 100 Mile Endurance Run, a nationally acclaimed event drawing participants from throughout the U.S. and abroad, other events include Ski Challenge, Bike Across Vermont, 50 Mile Run and Mountain Bike Race, and other events provided by independent sponsors and philanthropic organizations. Eighty percent of funding goes directly to program operations, and any person with a disability is welcome to participate, regardless of the person's ability to pay.

REFERENCES

1. Fine, A. (1988). Therapeutic recreation for exceptional children. Springfield, IL: Charles C. Thomas Press.

2. Wehman, P. (1979). Recreation programming for developmentally disabled persons. Baltimore: University Park Press.

ACKNOWLEDGEMENTS

Vermont Adaptive Ski and Sports would like to extend thanks to its donors, the Friends of VASS and members of the Vermont 100 Association, and most importantly to its volunteers. Each and everyone has given a special part of themselves to make VASS a successful sports and recreation program. It if weren't for the time, energy, and talent of the volunteers, VASS would not be successful.

Darlene Miller
Associate Professor
Vermont Technical College
Randolph Center, VT 05061
(802) 728-1345
dmiller@night.vtc.vsc.edu

The RESNA Prototype Listserv- an investigation into electronic communication

Stephen Sprigle, Ph.D.
RERC on Technology Evaluation and Transfer
SUNY-Buffalo

Abstract

A Listserv was created to permit the members of SIG-09 and SIG-11 to communicate with each other via the Internet. After three months of usage, a few characteristics of the list have emerged. The 75 members are mainly from the US, but also include members from Canada, Australia, Sweden, the UK and the Netherlands. The list averages 2 messages per day, but nearly 40% of these were submitted by 2 members. The messages included clinical problem solving, professional opinions, and announcements of interest.

Background

The benefits of increasing communication among Resna members is currently being discussed by the Board of Directors with input from an ad-hoc committee of SIG chairs. Several options exist including setting up a computer bulletin board, creating a Gopher specific to Resna, and establishing a Listserv for members. The latter option was chosen by SIGs 09 (Wheeled Mobility and Seating) and 11 (Computer Applications) to try out a Listserv as a means to discuss issues. A Listserv offered the simplest means of 2-way communication, and could be tried, risk-free, as a means to collect information as the Resna leadership discusses options of the organization as a whole.

Listserv is short for 'list server', a system designed in 1986 to facilitate electronic discussions. Listservs evolve around people with a common interest. St. John's University coordinates over 25 lists focusing on disability and healthcare issues, including lists discussing ADD, amputation, low vision, and TBI. Members communicate with each other by mailing a message to the list address. The Listserv software then distributes the message to all the members of the list. Members receive mail sent by other members and can reply to the List to share their responses. A private discussion through regular electronic mail is always an option for the members who do not want to post to the entire list membership.

Objective

A Listserv was set-up for members of SIGs 09 & 11 to experiment with electronic communication and identify the benefits and shortcomings of this means of communication.

Approach

On October 1, 1994, the RESNA Prototype Listserv was created through St. John University's Electronic Rehabilitation Resource Center. The list was initially announced via a mailing to all SIG-09 members and to the SIG-11 e-mail list. SIG reports in the Resna News also announced its formation. The RESNA List was designed to reflect its prototypical nature and to protect the rights of Resna members involved in the trial. The list options included:

- Private mailings: only list members are able to send mail to the RESNA List
- Subscriptions are controlled by the Listowner- he receives messages from people interested in joining and, if they are RESNA members, he subscribes them. Initially, the list was open and people could subscribe themselves. This capability was removed to limit the trial to Resna members.

- Private membership: only members can review the membership list
- Private Archives: only members can access the message archives and files- all messages sent to the list are stored in the archives and can be retrieved by members; in addition, files can be sent to the list for storage and subsequent retrieval by members.
- Open mailings: messages are not monitored before being sent to the membership

Members were instructed to customize their subscriptions in a number of ways. The most common option is changing the method of receiving mail. Four options exist:

MAIL:(the default) members receives a mail message for each post to the list

NOMAIL: members can set this option when going on vacation so no messages arrive - they can then retrieve the archives to review list traffic missed.

DIGEST: members receive only one message per day which contains all the posts sent to the list that day; this option is popular with members who pay for each Internet message they receive.

INDEX: members receive one daily message which lists the subjects of all the posts to the list. They can access the archives to review messages of interest.

Results

The membership is somewhat diverse. Of the 75 members, 63 are from the US, 7 from Canada, 2 from Australia, and 1 each from Sweden, the UK and the Netherlands. Ten members access the list from private computer services (7 via AOL, 3 via CompuServe). Most members (55%) have addresses from universities (.edu extension), but many access via private companies (.com) and public organizations (.org). Only two people have unsubscribed from the Listserv in the first 3 months of operation.

Over the first 3 months of existence, 175 messages have been sent for an average of 2 messages per day. Only 37 of the 75 members have sent a message and 2 members accounted for nearly 40% of the messages. The distribution of messages sent by people was:

# of messages	# of members
>20	2
10-20	2
5-9	5
3-4	8
1-2	20

Analysis and descriptions of other Listservs refer to leaders, regulars, contributors and lurkers. Most RESNA list members chose to 'lurk' rather than post, and 2 members could be considered leaders. In fact, these 2 members were heavily involved in the design and set-up of the list. However, 10% of the membership could be considered regulars and this number should increase as more members become comfortable with the list.

The messages sent to the list included clinical questions followed by answers and suggestions, announcements of interest forwarded by list members, discussion of Resna conference issues (courses, papers, etc.). Clinical issues included questions regarding a specific client, equipment compatibility, and requests for reference material.

To distinguish between issues relating to SIG-09 and SIG-11,a simple method has been adopted. The SIG is listed in the subject line to allow the members to skip over messages in which they might not be interested. Two such subject headings might be:

09- exceedingly important issue
11- uninteresting drivel

Members are informed if the nature of the post is SIG-specific and can act accordingly.

RESNA List maintenance is done by the *Listowner*, a person provided privileges by the Listserv administration. This person's responsibilities are generally limited to housekeeping and answering questions. The RESNA Listowner has answered questions about members' subscriptions, mail options, access to the archives, and responded to requests for subscriptions. Periodically, the mail server has had problems delivering to a particular subscriber (i.e., local machine goes down, local mailbox is full). When this problem persists, the Listowner has to intervene and either contact the member or delete him/her from the list.

Discussion.

The RESNA Prototype List is still in its infancy. Members are still getting comfortable with the Internet, the list and participating on both. Hopefully, a greater percentage of the subscribers will participate, but evidenced by the lack of people unsubscribing, the membership seems content at this time.

Resna, the organization, needs to decide its place on the Internet, and address many tradeoffs in defining its presence. The RESNA list can be opened to the public, the entire Resna membership or maintained as a list for SIGs 09 & 11. A single list for all the SIGs might be viewed as tough to manage since subscribers will be exposed to posts from other SIGs, but creating a list for each SIG might defeat the objective of increasing communication. Alternative means, such as a RESNA Gopher or BBS might provide easier access to information, but fail to permit dialog. Many tradeoffs exist for all electronic communication options.

Regardless of the decision, the existence of the RESNA Prototype Listserv has been a worthwhile opportunity to experience electronic communication and collect information in hopes of facilitating an informed decision.

References

Zenhausern R, The Bitnet Database and the Virtual Personality of a List, St. Johns University

Acknowledgments

- Thanks to David Jaffe, and the many other Resna members who added input to this process.
- Without the efforts and mentoring of Dr. Bob Zenhausern from St. Johns University, the RESNA List, and therefore, this paper, would not exist. Thank you, Dr. Z.

For further information, please contact:
Stephen Sprigle, Ph.D.
Center for Assistive Technology
SUNY- Buffalo
Buffalo, NY 14214
sprigle@acsu.buffalo.edu

SIG-16
Gerontology

AN ASSISTIVE NEEDLEWORK STAND

Kathryn E. Waldera, MSBE, Robin W. McCall, Laura Oak, CTRS
Rehabilitation Institute of Chicago

ABSTRACT

The design of an assistive needlework stand is presented. It clamps to a work surface and is mounted on a gooseneck so that its position in infinitely adjustable in space. The needlework stand is durable, and can accept needlework hoops of any size. A major design goal is that a disabled individual be independent in its use. Fabrication details are provided so that this needlework holder can be duplicated.

BACKGROUND

Leisure and recreation can improve quality of life by providing relaxation, self-satisfaction, exercise and creative outlets. When a person experiences a disability, he or she can be overwhelmed with physical, cognitive, social and emotional changes. Therapeutic recreation can enhance the rehabilitation process when success and satisfaction derived from recreation activities motivate an individual to succeed in other areas of life. An individual can be returned to his or her pre morbid leisure pursuits by adapting activities or adapting equipment to allow participation and/or independence.

Recreation therapists initially asked engineers in this facility's Rehabilitation Engineering Department to develop a needlework holder for an individual who had experienced a CVA and subsequent hemiplegia. Before she experienced the CVA, this woman enjoyed quilting, cross-stitch and embroidery. The commercially available needlework products were not appropriate for the client for several reasons. The clamping mechanism on one type of needlework stand was not secure enough to hold the needlework steady. The use of this clamp was also limited because it would only fit on tables less than an inch thick. One commercially available product was found which had a very sturdy clamping mechanism. However, the hoop was mounted on a dowel rod which had no adjustability. The client needed a needlework hoop mounted on a gooseneck for maximum flexibility. This client also wanted a needlework stand which would easily accept many different size needlework hoops. The commercially available products only provided one hoop.

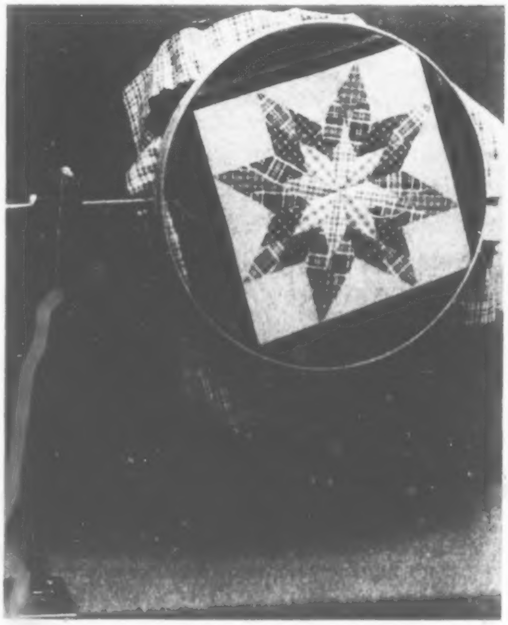


Figure A. The Assistive Needlework Stand

STATEMENT OF PROBLEM

A needlework stand is needed which can be used independently by an individual with a disability. This needlework stand should be attached to a gooseneck for maneuverability, and the gooseneck should be able to be clamped to tables of varying thicknesses. Additional design goals include that the needlework holder be light-weight, durable and low cost.

RATIONALE

This needlework stand was developed because commercially available products did not meet the needs identified by the recreation therapists.

DESIGN

After studying several commercially available products, the adapted needlework stand was initially developed in the summer of 1994 by this institution's Rehabilitation Engineering Department. It was evaluated with clients seen in the Therapeutic Recreation Department. Modifications to the clamping system were made after the client trials.

FABRICATION/DEVELOPMENT

The adapted needlework stand uses the following readily available materials:

10" plastic embroidery hoop

3/16" thick aluminum flat stock

1/4" diameter aluminum rod

7/8" diameter Delrin rod

plastic knob, 10-32 male threads

Microphone Stand Adapter (Radio Shack #33-371)

13" Gooseneck (Radio Shack #33-330)

Microphone Mounting Flange (R. Shack #33-332)

Steel Bench Clamp (McMaster-Carr #5251A4)

1/2" diameter Delrin rod

2 1/4" ID aluminum split shaft collars

fasteners (machine screws, washers, lock nuts)

1. 10" Plastic Embroidery Hoop (see Fig. B)
Drill two #11 holes, 3/4" apart, through larger hoop. Counter sink the two holes on the inside of the hoop for two 10-32 x 3/4" flat head machine screws.

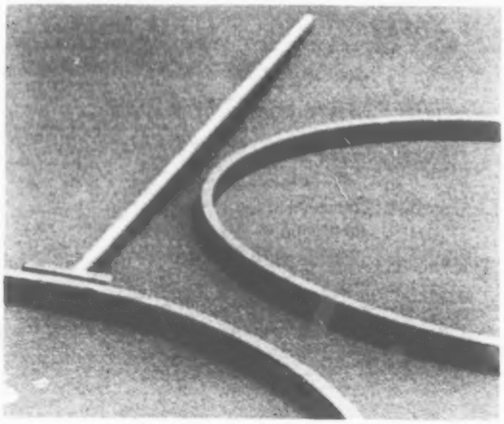


Figure B. Embroidery Hoop and Aluminum Rod

2. Aluminum Strip and Rod (see Fig. B)
Cut the 3/16" thick aluminum flat stock to the dimensions 1 1/4" by 1/2". Drill two #21 holes 3/4" apart. These holes will be tapped for 10-32 machine screws. These holes must line up with the holes drilled in the larger embroidery hoop. Cut a 12" long piece of the 1/4" diameter aluminum rod. Weld this rod to the center of the aluminum strip, normal to the surface. Round off the free end of the aluminum rod. Note: If more than one hoop will be used, more than one of these assemblies should be made.

3. Delrin Rod (see Fig. C)
Cut a 1 3/4" long piece of the 7/8" diameter Delrin rod. Drill a 1/4" hole through the center of the Delrin rod. This hole will accept the 1/4" aluminum rod. Drill a #21 hole through the center of the side of the Delrin rod. This hole must be perpendicular to the 1/4" diameter center hole. Tap this for the 10-32 plastic knob. The plastic knob will be tightened onto the aluminum rod so that it holds the rod in place. Fit the 7/8" diameter Delrin rod into the microphone stand adapter.

4. Microphone Stand Adapter (see Fig. C)
Replace the pivot screw with a 1/4"-20 x 1" round head machine screw, using two 1/4" washers and a lock nut. Tighten this so that the microphone stand adapter can still pivot. Drill two #21 holes in each side of the microphone stand adapter, 1/4" deep into the Delrin rod. Tap these holes for two 10-32 x 1/4" machine screws. These two screws will hold the Delrin rod securely in the microphone stand adapter.

5. 13" Gooseneck (see Fig. C)
Screw the 13" gooseneck into the microphone stand adapter. Drill a #11 hole through the threads of both the microphone stand adapter and the gooseneck. Insert a 10-32 x 1" machine screw through this hole and tighten, using two #10 washers and a lock nut. This screw is needed to lock the gooseneck in place. Without it, the gooseneck will unscrew from the microphone stand adapter when the embroidery hoop is in use.

6. Microphone Mounting Flange (see Fig. A)
Screw the other end of the gooseneck into the microphone mounting flange. Drill a #11 hole through the threads of both the microphone mounting flange and the gooseneck. Insert a 10-32 x 1" machine screw through this hole and tighten, using two #10 washers and a lock nut.

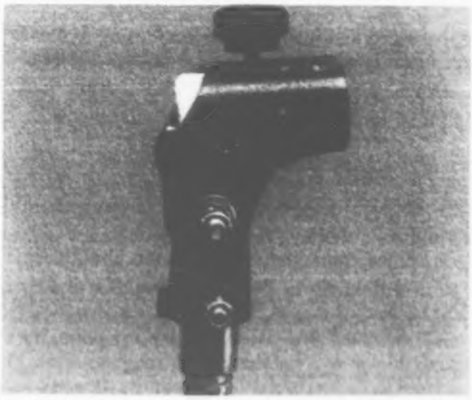


Figure C. Modified Microphone Stand Adapter

7. Steel Bench Clamp (see Fig. D)
Cut approximately 2" off the front of the steel bench clamp. This is done to reduce the size and weight of the clamp. Drill three #19 holes to match the three holes in the microphone mounting flange. Countersink these holes on the bottom side of the clamp - the side which will be touching the table. Attach the microphone mounting flange to the steel bench clamp using three 8-32 x 1/2" flat head machine screws and lock nuts.

8. Steel Bench Clamp Handle (see Fig. D)
Cut a 1 9/16" long piece of the 1/2" diameter Delrin rod. Drill a 9/32" hole through the center of the Delrin rod. The Delrin rod will slip over the handle of the steel bench clamp. The Delrin rod is held in place using two 1/4" ID split aluminum shaft collars, which are tightened on the steel bench clamp handle, on each side of the Delrin rod. The larger diameter handle is easier to use by an individual with limited hand strength.

EVALUATION

Client use has demonstrated that this adapted needlework stand is durable and adjustable. The individual for which it was first developed was independent in its use except for the initial setup of putting the fabric into the hoop.

DISCUSSION

Several improvements to the design of this needlework stand have been identified. First, the steel bench clamp is not only the most expensive component of the design, it is also quite heavy. A lighter version of this clamp would make the assembly easier to manipulate independently by someone with weak upper extremities. A smaller clamp may also reduce the cost.

Second, since not everyone has access to a welding station, a different means of attaching the 1/4" rod to the needlework hoop is desirable. Perhaps, one end of the 1/4" rod could be drilled and tapped and a flat head screw could be used to attach the needlework hoop to the rod. Locktite would be recommended to strengthen this joint.

Additional needlework stand options were identified by the recreation therapists for future design and development. These include attaching a magnifying glass to the needlework hoop for those with diminished vision and devising a means of rotating the needlework hoop in the stand for easier management. For a floor-mounted version, the gooseneck could be bolted to a microphone stand instead of a clamp. The microphone stand can be purchased from Radio Shack (part no. 33-320) for less than $25.

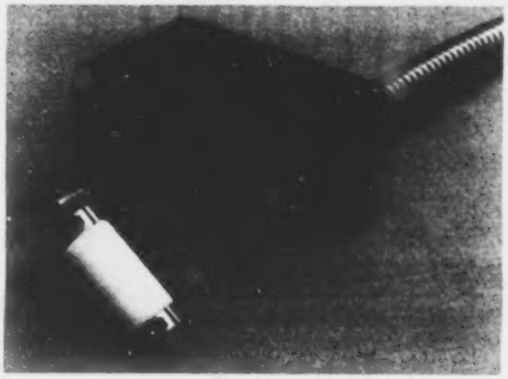


Figure D. Steel Bench Clamp and Modified Handle

CONCLUSION

The adapted needlework stand can enable an individual with a disability to participate in hobbies including quilting, cross-stitch and embroidery. The needlework stand is durable, easily adjustable and accepts needlework hoops of all sizes. It can be mounted on tables up to two inches thick. The design can be duplicated using tools found in many rehabilitation engineering or plant engineering departments.

SUPPLIERS:

McMASTER-CARR SUPPLY CO.
P.O. Box 7690
Chicago, IL
(708) 833-0300

RADIO SHACK

Kathryn E. Waldera, MSBE
Rehabilitation Institute of Chicago
Rehabilitation Engineering Department
345 E. Superior St. - Room 1441
Chicago, IL 60611
(312) 908-8566

BEST COPY AVAILABLE

ENABLING HOME ENVIRONMENTS: STRATEGIES FOR AGING IN PLACE

Edward Steinfeld, Arch D., Professor of Architecture
Scott M. Shea, M. Arch, Research Associate
Rehabilitation Research Center on Aging, State University of New York at Buffalo

Abstract

Environmental barriers can significantly reduce the independence of older people with disabilities living in a residential setting. Removing these barriers through home modification is one way to increase independence. This study focuses on the effectiveness of technical assistance in helping people to make modifications, and the reasons why modifications are not made. Recommendations for improvements to service delivery are proposed based on the study findings.

Research Goals and Background Issues

Potential barriers to the accessibility, safety, security and usability of home environments for older people with disabilities are well known (see Pynoos, 1987 and Watzke and Kemp, 1992). As older people "age in place", these barriers present serious threats to independence and increase caregiver burden. Many methods for eliminating barriers and creating enabling environments have been proposed. However, the needs of individual households vary significantly and they differ from those of younger people with disabilities. There is a need for information on the types of barriers that "handicap" older disabled people, the specific interventions that should be high priorities and the level of acceptance of interventions among the older population. Such information can be used to identify priorities for policy, innovative design concepts, service programs and design of assistive technology. It can help to prevent disability among the older population and increase autonomy.

This paper presents findings from the second phase of a multi-year research study concerned with the identification of barriers to aging in place and consumer acceptance of actions to remove those barriers. A previous publication reported on the first phase of the research (Steinfeld and Shea, 1993). The research reported here focuses primarily on the reasons why participants do not implement recommendations of professionals, particularly those that they themselves agree are a high priority.

In an earlier phase of this study we could not explain the priorities consumers gave to recommendations on the basis of cost alone. By analyzing consumer priorities and from informal interaction, we obtained insight into the decision making process (Steinfeld and Shea, 1993). From a cost - benefit perspective, interventions are valued if their benefit outweighs the cost compared to other alternative methods of coping, such as changing behavior. In a risk assessment model, the perceived risk associated with some barriers may be greater than with others, and may be misplaced. Barriers perceived as having low risk are not viewed as real problems. In a cognitive dissonance model, some problems are perceived to be unsolvable and, thus, expectations for resolution are lowered in order to accept the situation more easily. In a social construction model, accepting the need for an intervention is a "reconstruction" of self image, an acknowledgment to others that one can no longer function effectively without adjusting relationships with the everyday world. Denying the need for intervention, on the other hand, presents a courageous image - "It's tough, but, I can handle it." As we began the next phase of our research, we realized that there are differences between establishing priorities and actually committing resources to action, thus we considered two other decision making models. The economic constraint model acknowledges that some individuals simply do not have the ability to pay for an intervention, even if they place a high priority on it. Furthermore, in certain cases, an item might be perceived as too expensive when in fact it is affordable. The stress management model is based on the premise that making a change requires some expenditure of psychic resources and energy; some things are perceived as "too much trouble", despite their obvious value. Because of the effort involved, however slight, a change is unacceptable regardless of the impact it might have on their life in the future.

Methods

The first phase of our work obtained descriptive data about the extent and type of barriers to aging in place found in the homes of a sample of older people with disabilities. A barrier was defined as an environmental feature that reduced functional capacity or put a person at risk. We identified 4 categories of barriers: activities of daily living, safety, security, and the structural deficiencies. Barriers were identified using a self report method administered as part of a comprehensive Consumer Survey conducted by the RERC on Aging (Mann et al., 1994) and a free home assessment service completed in homes occupied by people selected from the Consumer Survey sample. Recommendations for interventions through home modifications and other related services were prepared and discussed with each individual in order to identify priorities. The participants were alternately assigned to one of two groups as they were recruited. Group One received only the free home assessment and Group Two received additional technical assistance and referral services to help implement any of the recommended interventions. In the second phase, a follow up interview was conducted by telephone approximately 18 months later to identify which additional recommendations had been implemented. For each recommendation that was not implemented, the individuals were read a list of possible reasons and asked to tell us which statement most closely matched their own reason for not carrying out the recommendation. The reasons were based on the decision making models described above but worded in everyday language. Open ended responses were also solicited if the respondent felt our choices did not apply. Most of the open ended responses fit easily into one of the existing categories. All the participants in the study were over 62, had a disability and lived in non-institutional community housing in the Buffalo metropolitan area. A wide range of disabilities was represented.

Findings

Table 1 shows the total number of recommendations that were implemented. Barriers counted in Phase One were completed prior to the priorities interview and were considered high priority barriers by default. Phase Two data includes the additional actions that were completed after the priorities interview and prior to the follow up.

The individuals in Group Two implemented almost twice as many recommendations as those in Group One by the end of Phase Two. This would seem to indicate that technical assistance and referral services were helpful for resolving problems. However, roughly the same ratio held for the number of barriers resolved by the end of Phase One, before any additional services were actually provided. This indicates that the people in Group Two were generally more inclined or more able to change their environments than those in Group One.

phase	1			2			**Total**
group	1	2	total	1	2	total	
#barriers	321	426	747	321	426	747	747
#actions	30	54	84	19	33	52	136
%	4.0	7.2	11.2	2.5	4.4	7.0	18.2
#hipribar	101	188	289	101	188	289	289
hipri %	10.4	18.7	29.1	6.6	11.4	18.0	47.1

Table 1. Frequency of Actions

In addition, the number of recommendations implemented decreased over time. This is contrary to what one would expect if providing technical assistance and referral services are effective as a sole intervention. However, this finding does suggest that assessments on their own have an impact in increasing the rate of modifications. The initial assessment apparently focused participants' attention to problems and encouraged them to act.

Overall, only 18.2% of the barriers identified were resolved. However, of the 747 barriers encountered, 289 were considered a high priority and 47.1% of these were resolved. Thus, older people are willing to devote resources toward improving their home environment if they perceive barriers to be serious but they will not devote resources to low priority problems. What are the reasons for the lack of resolution for over half of the high priority barriers? Answering this question can help us discover ways to increase the rate of problem resolution.

An unanticipated reason for inaction was discovered during the interviews, perceived lack of control over the circumstances. This reflects a model of decision making based on autonomy. The individual wishes to resolve the problem but is unable to do so because others have control. This can be attributed in part to respondents living in rental properties. They were reluctant to approach a landlord or had already had a request refused and were hesitant to press their case. Roughly the same number of homeowners gave autonomy as a reason for not taking action. These people all cited family members who were unresponsive to their requests for assistance. Despite owning the home, they were dependent on others to make improvements. However, these homes had fewer barriers.

model	**n**	**%**	**revised %**
economic constraint	25	31.6%	31.6%
stress management	19	24.1%	24.1%
cognitive dissonance	11	13.9%	
social construction	5	6.3%	
self concept	16		20.3%
autonomy	10	12.7%	12.7%
risk assessment	7	8.9%	
cost benefit	2	2.5%	
deferred priority	9		11.4%
Total	**79**	**100.0%**	**100.0%**

Table 2. Frequency of Reasons for Inaction

Table 2 shows the frequency distribution of reasons given for inaction on high priority recommendations. Overall, the barriers that were identified and the proposed solutions were perceived as relevant and important, as indicated by the extremely low number identified as cost-benefit, or "not making enough of a difference". While economic constraint was the most frequent reason given for inaction on a recommendation, 68.4% of the barriers were left unresolved for other reasons. Cost is clearly not the only reason why individuals do not make modifications. Stress management was the next most cited reason reflecting another dimension of resource constraints. The frequency of the other reasons were considerably lower than these two.

It is possible that our original categories masked the relative importance of different reasons. Upon reflection, we noticed a close affinity between the risk assessment and cost benefit models of decision

BEST COPY AVAILABLE

making. In both cases, the level of perceived benefit can trigger action. Until that benefit is perceived to be significant, either in terms of value or reduced threat, action will be deferred. Likewise, the cognitive dissonance and social construction models are both concerned with self concept. In the former, individuals do not act because they deny a change in status and in the latter, because they blame their limitations as the cause of the problem. Inaction, in both cases, can be attributed to an unrealistic assessment of self. Thus, we revised the categories to collapse these four models to two, "deferred priority" and "self concept". Conceived this way economic constraints and stress management are still the top two, but self concept is not far behind.

Conclusions

Over half of the barriers that were identified as high priorities by the participants themselves were not resolved at the end of the study period. While, in one sense, it is encouraging to find out that households that have older people with disabilities will take action to remedy problems, a higher level of resolution would be desirable. What can be done to increase the rate of action? Our findings indicate that technical assistance and referral services alone are not sufficient to help improve the rate of action. A different type of intervention is needed.

The results show that there are three major reasons why the older people in our sample did not take action on a recommendation for a home modification. The first is that the economic cost of implementation was perceived as being outside their means. The second was that the physical and psychic energy required to implement the recommendation was perceived to be beyond their capacity. Third, implementation required a realistic assessment of self, specifically the belief that a change in the environment can make a difference in one's quality of life. Such a reassessment was not acceptable in many cases. Two additional but, still important reasons are that the ability to make the change was out of the control of the respondent and that the barrier was not perceived to be important enough yet to demand action.

Previous demonstration studies on this topic have not only provided assessments but also either offered to make modifications free of charge or provided cash grants (see for example Trickey et. al.). These studies reported higher implementation rates. Our findings confirm that the availability of financial assistance is the most important incentive for insuring action. It is important to note, however, that the previous studies did not compare the rate of implementation prior to and after the service intervention. Our findings indicate that this should be an important methodological component of intervention studies.

The research has several implications for improving the delivery of home modification services to support aging in place. First, more attractive financing mechanisms need to be developed. A funding program that could address all the implications of aging in place together and provide a menu of health care, social service and shelter options would increase flexibility in the use of existing funds and thereby address the diverse needs of households. Second, service providers should reduce the stress of implementing home modifications by providing "one stop shopping" for all related services and maintaining high quality and reliability standards that will promote trust and security. Third, ways to reduce the cost of service delivery are needed. Fourth, case managers and outreach personnel need to address the issue of lack of control with strategies to encourage landlords and families to fulfill their obligations. Fifth, educational programs are needed to improve the awareness of aging in place and the advantages of home modifications for the older consumer. Sixth, there is a need to develop low cost, "hassle free" and age appropriate solutions to the common barriers to aging in place.

References

Mann, W. C. et. al. The Rehabilitation Engineering Center on Aging. *Technology and Disability*. Butterworth-Heinemann: Stoneham, MA. 1994. pg. 284

Pynoos J, Cohen E, David LJ, Bernhardt S. Home Modifications: Improvements that extend independence. In Regnier V, Pynoos J, eds. *Housing the Aged*. New York: Elsevier Science Publishing Co., Inc., 1987

Steinfeld, E and Shea, S. Enabling Home Environments: Identifying Barriers to Independence. *Technology and Disability*. Butterworth-Heinemann: Stoneham, MA. Fall 1993. p. 69

Trickey, Francine et.al. Home Modifications for the Elderly: which ones do they want? Which ones will they use? *WINDOW on Technology*. vol. 7, no. 4. pg. 8

Watzke, J.R. and Kemp, B. Safety for Older Adults: The role of technology and the home environment. *Topics in Geriatric Rehabilitation*. Aspen, 1992

This research was funded by NIDDR as part of the RERC on Aging at the State University of New York at Buffalo.

Edward Steinfeld
Adaptive Environments Laboratory
390 Hayes Hall
SUNY at Buffalo
Buffalo, NY 14214
716-829-3484 ext. 329
Arced@ubvms.cc.buffalo.edu

The Development of a Primary Care-based Assistive Technology Recycling Center

Paula Guerette, PhD, William Moran, MD, MS, Catherine Messick, MD, MS,
S. Bryant Kendrick, DMin & Brenda Kearney, BS
The Bowman Gray School of Medicine, Winston-Salem, North Carolina

ABSTRACT

For older people with functional impairments, it is often difficult to obtain assistive technologies to facilitate daily activities. The Community Care Coordination Network (CCCN) is a computerized method to link community and hospital-based services with primary care providers. The CCCN provides methods for determining unmet needs of older adults living in the community. However, many of these needs cannot be met through current health care delivery programs. A method established as part of the CCCN to address unmet needs for assistive technology is the development of a community-based assistive technology 'recycling center.' This paper describes the process currently underway for developing this program.

BACKGROUND

Many older adults living in the community are disabled as a result of chronic health conditions such as arthritis, stroke, or diabetes. These people often use assistive devices or require the services of multiple care providers (e.g., home health nurse, personal aid, physical therapist, physician) in order to maintain their independence in the home. Difficulties in coordinating services can result in duplication of services or in lack of appropriate provision of assistive devices or services.

To improve coordination of care to individuals with functional impairments, a computerized medical record system has been implemented at the Reynolds Health Center (RHC), a large community health center in Winston-Salem, NC (1). The database contains patient medical information, as well as supplemental information such as patients' functional status, home environment, assistive devices used, services received, and unmet needs in daily physical and instrumental activities. Electronic linkages have been established with a consortium of community based providers, including the emergency and social work departments at two area hospitals, the Department of Social Services, Senior Services, and four home health agencies; this consortium is known as the Community Care Coordination Network (CCCN) (2). Members of the CCCN have remote access to patient information to help them with clinical decision-making.

An important feature of this network is the ability to generate electronic 'alerts' to the primary care provider when a patient has an important health care event such as an emergency room visit or a hospitalization. Often, such patients could benefit from follow-up assistance. For example, an older woman who falls and fractures a wrist might benefit from assistive devices such as eating, cooking or dressing aids. Through an evaluation of the reported functional data and via the electronic alerts, the CCCN is able to systematically identify older patients' needs for assistive devices and services.

Unfortunately, there is often no existing means for addressing these needs within the current health care system. For example, for those older adults who need assistive technology, current policies typically lead to a lack of recommendation and provision. Medicare, the primary means of reimbursement for AT for older adults, currently reimburses only a limited range of assistive technology. A wide variety of other important devices (e.g., a communication device for an aphasic stroke survivor) are not deemed 'medically necessary' and are therefore not funded. The lack of provision of assistive technology to older people is sizable. In considering older adults' unmet needs for assistive technology, a recent study found that 45% of older people indicate that they have an *unmet* need for assistive devices (3). This represents over a million older people who report unmet needs.

One important policy shift that would enable more older people to obtain assistive technology is a move from individual ownership of devices to *community access*. It may not be reasonable to expect that Medicare will increase its scope of coverage. However, an alternative approach seeks to extend the lifespan of existing technology through community access to technology. Rather than funding additional assistive technology for individual older adults, programs that support the development and promotion of community 'technology recycling centers' may be a more important mechanism for disseminating technology to individuals.

OBJECTIVES

- To develop a primary care-based computerized intervention system to routinely identify unmet needs for assistive technology, and
- To develop a community-based program to obtain, recycle and disseminate assistive technology to older adults with functional impairments.

APPROACH

The current program proposes to develop a community-based intervention program to identify unmet needs for assistive technology, and to obtain and recycle unused devices back into the community. To date a total of 225 older adults with functional impairments have been enrolled in the CCCN. These people identified numerous unmet needs in various ADL and IADL tasks. Some of these needs could be addressed with appropriate provision of assistive technology.

For those patients who have identified needs, a number of options for assessment will be available. Preliminary assessment of appropriate interventions, including assistive technology, will be performed by home health nurses trained in assistive technology. Individuals with more complex problems will receive a comprehensive geriatric assessment, including evaluation by a rehabilitation professional such as a physical or occupational therapist.

A pilot project has been initiated under the Claude Pepper Center for Older Adults to develop community-based interventions to address unmet needs and promote functional independence. One part of this project aims to establish a technology clearing house for community-based recycling and dissemination of assistive technology. An initial technology loan closet, supported by funds from the NC Assistive Technology Program, serves as the foundation for this clearing house. The equipment includes a wide variety of assistive technology, including aids for feeding, grooming, toileting, mobility/transfer, communicating, and environmental control. Currently, the loan closet is based at the Reynolds Health Center, a location where primary care physicians can become exposed to the range of available assistive devices, and patients (many of whom have transportation difficulties) can easily access and try the devices.

During the next phase of the project, requests will be sent to local home health agencies, service and charitable organizations, and private donations to solicit unused equipment. Older volunteers will be included to help with the process of obtaining, cleaning and refurbishing used equipment. In addition, a quarterly newsletter highlighting local assistive technology needs and advertising available secondhand devices for sale will be produced and distributed to area consumers, older adult groups, home health agencies, and other professionals.

DISCUSSION

In considering assistive technology, most devices usually have longer utility than the older person to whom a device was initially recommended. The community-based assistive technology 'recycling center' could increase the lifespan of previously purchased assistive devices, and could provide devices currently unavailable through traditional funding sources to older individuals for the duration of time that they need it. Once a device is no longer needed, that piece of equipment could be returned to the clearing house for cleaning, refurbishing, and distribution to another older individual who might need it. This type of program would provide a cost effective means of addressing the needs of a wider range of older people.

REFERENCES

1. Moran, WP, Wofford, JL, Hamrick, V, Byers, BT, Cooper, J, Doby, J, FitzGerald, J, Spence, C & Velez, R. (1993). Implementing computerized tracking at a community health center: Challenges and solutions. In *Proceedings of the Seventeenth Annual Symposium on Computer Applications in Medical Care*. New York: McGraw Hill, Inc.

2. Guerette, P, Moran, W, Messick, C, Wofford, J & Velez, R. (1994). Use of technology to improve service to older adults: A computerized community care coordination network. In *Proceedings of the RESNA '94 Annual Conference*, Nashville, TN.

3. LaPlante, MP, Hendershot, GE & Moss, AJ. (1992). Assistive technology devices and home accessibility features: Prevalence, payment, need and trends. *Advance Data*, 217, Center for Disease Control, National Center for Health Statistics.

ACKNOWLEDGEMENTS

The CCCN is funded by grants from the Robert Wood Johnson Foundation 'Building Health Care Systems for People with Chronical Illness' and 'Generalist Faculty Scholars' programs, by grants from the Kate B. Reynolds Poor & Needy Trust, and by a grant from the National Institute on Disability and Rehabilitation Research to the NC Center for Accessible Housing.

Paula Guerette, PhD
Department of Internal Medicine/Gerontology
Bowman Gray School of Medicine
Medical Center Boulevard
Winston-Salem, NC 27157

SIG-17
International Appropriate Technology

RAMPING THE SIBERIAN STEPPE: WHEELCHAIR MARKETING IN NOVOSIBIRSK, RUSSIA

Marc L. Krizack, Wheeled Mobility Center at San Francisco State University

ABSTRACT

A year and a half after the Wheeled Mobility Center (WMC) began its project to set up wheelchair factories in Siberia, there continues to be an overwhelming need for wheelchairs in Russia. Economic demand, however, is much smaller because soaring inflation, government austerity measures, and a government monopoly on wheelchair purchases with government funds has stifled wheelchair sales. This is the dilemma now confronting the nascent wheelchair building industry in Novosibirsk, Siberia's largest city.

INTRODUCTION

The author presented a paper at RESNA '94 outlining WMC's strategy for developing a competitive system of wheelchair production in Russia. The strategy was based on the assumption that Russia's transition from a planned economy to a market economy posed unique problems for an emerging wheelchair industry. The solution, WMC believed, was to create "managed competition" by setting up three competing privately owned wheelchair factories. Since RESNA '94, WMC has altered its strategy in three ways. First, in the face of very difficult economic conditions, WMC has limited its project to two factories. Second, WMC has shifted funds away from production and toward marketing. Third, WMC has made greater efforts to develop an active movement of people with disabilities, with a special emphasis on organizing disabled women.

BACKGROUND

In 1990, WMC introduced wheelchair design and production technology to the Aeroflot Helicopter Repair Facility (HRF) in Novosibirsk. At the time there was only one state-owned wheelchair manufacturer in the entire Soviet Union, producing just two styles of wheelchair. WMC's work with the HRF began during the first phase of Perestroika, when worker cooperatives were forming within state enterprises as a first step toward private enterprise. Producing wheelchairs made sense to HRF management because the HRF had access to most of the necessary materials, owned the tools and equipment, and had a skilled labor force.

In 1992 HRF management shut down most of its cooperatives, partly because cooperative members were earning much more than their non-coop counterparts. The presidents of two of those cooperatives joined together to form a private business, SibMedDesign (SMD) and asked WMC's help to initiate wheelchair production.

The HRF and SMD enthusiastically embraced the opportunity to go into wheelchair production because they expected the government, which had the money and the moral obligation, to purchase their output. A guaranteed market was critical to the HRF and its SMD spinoff because they knew very little about marketing. Under the Soviet system they never had to market their products because everything they built had already been sold by or to the state.

From 1991 to 1993 the HRF and SMD sold wheelchairs mostly to municipalities. However, they were unable to get the Department of Social Protection, equivalent to our state departments of rehabilitation, to purchase their chairs. The Department of Social Protection would only purchase chairs that had been "certified," and the government would certify only wheelchairs from their one factory in Stavrovo.

Then the Soviet state and economy collapsed. Even if the government monopoly could be cracked, the new austerity measures would preclude the government from becoming a major purchaser of wheelchairs. Rapid inflation was eating away at the pensions of disabled people, leaving them and their families with less disposable income with which to purchase wheelchairs. The market for wheelchairs was further stymied by the almost total lack of wheelchair accessible public transportation and the wide-spread architectural barriers.

DISCUSSION

Against these odds, WMC launched a strategy to promote civic activism among the Novosibirsk disabled community to create political pressure for reform in government policies toward people with disabilities. This strategy had two principal goals. The first was to encourage the Department of Social Protection to purchase wheelchairs made in

Novosibirsk. The second was to gain government funding for wheelchair accessible transportation and the removal of architectural barriers. The idea was that better quality wheelchairs and better access would stimulate the market for wheelchairs in the same way the interstate highway system stimulated the demand for automobiles in the U.S.

With the help of a grant from World Learning/USAID, WMC has been working with the Novosibirsk Regional Disabled Sports Club FINIST (Phoenix) to develop this strategy. FINIST wheelchair riders have demonstrated to case workers and administrators in the municipal and regional Departments of Social Protection the advantages of SMD wheelchairs over government-made chairs. The government chairs are one-size-fits-all models that rarely fit, are often uncomfortable, cannot squeeze through doorways, are too heavy, and generally will not support an active lifestyle. They have the look and feel of a hospital. The SMD chair is at least ten pounds lighter and can be narrowed by the wheelchair rider while she is in it to get through tight bathroom and elevator doors. Quick release axles allow the rear wheels to be easily removed. When folded, the chair will fit conveniently into the trunk of a small Russian car.

Inside a Siberian wheelchair factory.

After the Department of Social Protection purchased government wheelchairs for some people who had requested SMD wheelchairs, FINIST activists complained loudly how their opinions should be considered since they are the ones who will use the wheelchairs. Bowing to pressure from the disabled community, and with the encouragement of a sympathetic administrator, the Regional Department of Social Protection agreed to purchase SMD chairs provided the chairs could meet international standards. SMD sent one of its chairs to be tested in the United States. When the test results show the chair has met or surpassed ISO standards, the Department of Social Protection will purchase its first SMD wheelchairs, and the government monopoly will be broken.

Yet government purchases will always be limited by the available funds, which will likely grow scarcer as Moscow further implements its austerity plans. So, to tap the private market, WMC is helping the Novosibirsk wheelchair factories develop contacts with foreign charities interested in purchasing wheelchairs made in Russia for sale in Eastern Europe and the former Soviet Union.

To stimulate the private domestic market, WMC and FINIST have been working successfully to gain wheelchair accessible transportation and to remove architectural barriers. Since March 1994, 20 disabled people have come forward as new community activists. In April 1994 a newly established executive committee of wheelchair riders successfully lobbied Spartak stadium management to build a wheelchair ramp and an accessible bathroom. They convinced the Department of Social Protection to purchase a small bus for them and to give them money to have equipped with a wheelchair lift. Social Protection also funded an accessibility survey of downtown Novosibirsk and the cost of drawing up the blueprints for remodeling a part of the stadium to create an independent living center.

A key component of WMC's strategy to organize the Novosibirsk Disabled Community is the "ARIADNA" disabled women's program, officially formed in November 1994. Conceived as a cross-disability organization, ARIADNA will help overcome disability-specific organizational divisions that have historically separated Novosibirsk's disabled community. Wheeled Mobility Center will help develop ARIADNA through a second grant from World Learning/AID. The new project, in cooperation with Planned Parenthood of Northern New England, will set up a consumer-directed Disabled Community Health Clinic in Novosibirsk. The two-year project will train medical professionals to recognize and treat the special medical needs of people with disabilities. The project will also train disabled Russians to provide on-going training through peer support and mentor programs to other disabled Russians and their families in the prevention and treatment of the secondary effects of disability, such as pressure sores and bowel and bladder problems, as well as reproductive health issues. With better health management, more places to go, and more activities to participate in, even people who own a government-built wheelchair will want a chair suitable for more active and independent use.

Recognizing that many disabled people and their families do not have the money to purchase a wheelchair outright, WMC and FINIST are establishing a consumer credit fund. WMC's experience over 15 years in more than 20 countries around the world indicates that the recipient of a free wheelchair is not motivated to keep the chair in good repair. Instead, he puts off paying for needed repairs expecting to get the next chair for free. The credit fund will help establish a minimum price equal to or greater than the maintenance cost, to encourage purchasers to pay for necessary and routine repairs to their wheelchairs.

Donations from private charities and other funding sources will be placed in the credit fund. The initial funds will be loaned to those who can make the largest down payments, then to those who can be expected to pay back the loan, then to those who can repay the loan partly in cash and partly through volunteer work in the disabled community. Finally, some funds will be reserved for those who will repay the loan only through volunteer work. Plans are to gain the government's support for this credit fund so that the money the government allocates for wheelchair purchases will pass through the credit fund. Otherwise, free wheelchairs from the government will undermine the credit fund's self-reliance philosophy and limit the fund's effectiveness.

FINIST has also begun a modest vocational training program which presently provides training in wheelchair repair, computers and English in the hope that future employment will help some wheelchair purchasers repay their loans.

SibMedDesign wheelchair made in Siberia

Finally, FINIST has set up a retail wheelchair store and a wheelchair repair service. In addition to regular repairs, this service will perform warranty work and in the process compile a record of design and production problems to help the factories improve product quality.

A market economy spawns a complex web of supporting social institutions. Because three generations of Russians have had little experience with a free market economy, the Wheeled Mobility Center has chosen to initiate a program of comprehensive economic and social reform as the most effective way to develop an indigenous wheelchair industry in Novosibirsk. It is an ambitious program, but in WMC's view, the only way to proceed in the former Soviet Union.

ACKNOWLEDGMENTS

Funding for this project has been provided by the United States Agency for International Development (USAID) through World Learning, Inc.

Marc L. Krizack
Russia Project Manager
Wheeled Mobility Center at SFSU
1930 Parker Street, Berkeley, CA 94704 USA
Tel/Fax (510) 548-3652
E-mail krizack@sfsu.edu

UCT COMMUNITY-BASED REHABILITATION TRAINING & RESOURCE CENTRE: A PRIMARY HEALTH CARE DEMONSTRATION PROJECT

David A Boonzaier, U. Cape Town and Groote Schuur Hospital

ABSTRACT

Community-Based Rehabilitation (CBR) has been adopted as the new Rehabilitative paradigm for supporting Primary Health Care by planners of South Africa's Reconstructed Health Service. In keeping with the principles of ALMA ATA and the WHO drive toward Health Care for all by 2000, we have generated a Community Extension Project which uses the resources of the University and Medical School for teaching and training of CBR assistants. The aim is to transfer, in problem-orientated workshop sessions, some useful pragmatic skills to people who are completely untrained but who, because of their closeness to their communities, are more socially attuned to the needs of their clients. We have been reasonably successful in the 18 month run-up since the inception of the project, in achieving this objective. We are looking for further funding to ensure sustainability and replicability elsewhere.

Since the renaissance in South Africa which was enabled by the lifting of economic sanctions, opening of non-governmental organizations for foreign aid and the free interchange of academic and other professional personnel, new possibilities for redesign of Rehabilitation Delivery Systems are helping to ensure a more equitable Health and Welfare Service.

Amongst the major deficiencies in the previously vertically-structured services, including Rehabilitation, were the disproportionately large resources (personnel and cost) spent on Tertiary (i.e. Specialist) in relation to Primary Care and the fact that all population groups, especially poorer rural communities were not getting equitable services, which were to a large extent urban and peri-urban in distribution. This often necessitated rural clients/patients to have to make long journeys to cities in order to address their rehabilitation needs.

Though the Regional Health Authorities were in theory responsible for delivering post-acute and chronic health care, including Rehabilitation, this intermediate level of professional (but not specialist) support and therapy was never adequately instituted.

With the change in government in April 1994, the emphasis has shifted away from Specialist Hospitals back to Primary and to some extent Secondary Health Care, in keeping with World Health Organization guidelines.

This has necessitated the urgent need for appropriate training for new cadres of Health Workers, at Primary Care level, in their respective communities. One such need is being addressed by the creation of a group of people to give attention to the full breadth of rehabilitation needs in their local communities. They will have adequate supervision and referral systems to ensure that sufficient trained therapeutic support would be available when problems beyond their competency were encountered. These new workers have come to be known as Community-Based Rehabilitation Workers (CBRW).

One of the biggest problems, from the inception, was to have sufficient teaching/training systems in place so that CBRWs could feel reasonably confident in providing their much-needed assistance. Several Non-Governmental Organizations established grass-roots service delivery systems in Townships near Cape Town, but it became obvious to those of us working on Technological aspects of Rehabilitation that unless these CBRWs got some training involving hands-on experience in solving simple seating, positioning, mobility problems, using simple ubiquitous materials and a reasonable amount of inventiveness, there would be a very long learning curve, causing a great deal of frustration and unnecessary hardship in the process.

The U. Cape Town CBR Centre

In order to address this serious training deficiency, we instituted a Pilot Project which we hoped, if successful, could be replicated in other communities elsewhere in peri-urban and country settings. Several projects world-wide were looked at for inspiration, including Project Projimo in Mexico, as well as the writings of authoritative people who were engaged in similar activities. We found three how-to books particularly useful in this regard: Low Costs Aids (AHRTAG), Disabled Village Children (Werner) and Helping Health Workers Learn (Werner and Bower) (ref).

The project was funded by the University of Cape Town and was entitled the **CBR Training and Resource Centre**. Initial seed funding was for two years but we will require further external support in order to continue. The aim of the project is to harness the capacity of the University/Medical School Staff, particularly those in Biomedical Engineering/Rehabilitation Technology, and Occupational and Physiotherapy, to give demonstration hands-on assistance and in-service training to CBRWs and to a lesser extent their support staffers. We in Biomedical Engineering have over the last 20 years developed considerable expertise and a good shopping list of simple device modifications and accommodations which could be communicated easily to CBRWs, who would typically bring problems including the clients and immediate caregivers to the Centre for evaluation.

We tried as much as possible to address generalities and pluralities and to attempt to pass on creative use of materials as core constructs rather than pedantically "solving" the problem at hand in isolation. This approach has been surprisingly successful and we find that to a greater extent CBRWs are not coming back with simple issues any more, but are clearly managing to take charge of most of the problems and solve them in the community. Every now and again they do return for certain not-easily obtained materials, such as velcro and foam, but we were surprised at the inventiveness of these previously untrained people once they had developed the necessary confidence in their own abilities. We call this the "teaching people to fish" approach - a sort of technological empowerment.

The resource centre part of the project is essentially to provide literature and simple-to-follow plans for self-help solutions to activities of daily living (ADL) problems including mobility, seating and positioning. This latter part of the project has not been as successful due to the lack of suitable facilities and staffing.

In the previous 18 months we have already addressed over seventy problems with the multiplier effect of these contact periods doubling as in-service training sessions, as well as therapeutic.

CONCLUSION:

We have demonstrated in this pilot project that effective training of CBRWs can be achieved at the same time as therapeutic/assistive technology delivery. This pilot project can be emulated in any developing country where reasonable proximity exists between a Regional Rehabilitation teaching/training Institution and a group of grass-roots community workers, and where both the trainers and the trained are enthusiastic, ready, willing and able.

ACKNOWLEDGEMENT:

Thanks are due to the Extension Service Committee of the University of Cape Town for providing seed-funding to buy materials for training and assistive device components, as well as a computer for the resource centre.

REFERENCES:

1. Low Cost Aids, AHRTAG (1988)
2. Disabled Village Children, David Werner, 1982 (Hesperian Foundation)
3. Helping Health Workers Learn, David Werner and Bill Bower, 1987 (Hesperian Foundation)

AUTHOR'S ADDRESS:

David A Boonzaier MBChB. DIC
Rehabilitation Technology Group
Biomedical Engineering Department
U. Cape Town Medical School &
Groote Schuur Hospital
Observatory 7925 SOUTH AFRICA
Tel.: + 27 21 4046117 Fax: +27 21 4483291
Email: BMVAL@ANAT.UCT.AC.ZA.

An Innovative, Low Cost and Effective Method for B/K Sockets Prescription and Fabrication

Kao-Chi Chung, Ph.D, Ju-Lei Wu and Shu-Zon Lou, MS
Institute of Biomedical Engineering, National Cheng Kung Univ. Taiwan

ABSTRACT

Prescription, fabrication and fitting of B/K prostheses for the amputee represent a difficult and complicated clinical and rehabilitation management in developing countries. This paper describes development of a cost-effective B/K socket fabrication system combined with Chinese herb intervention for residual soft tissue management in the process of socket fitting. More than 30 amputee has been treated with this method for B/K socket prescription. Clinical and subjective evaluation indicated that the system and treatment are clinical efficacy. This development can be applied directly to A/K amputation.

BACKGROUND

Prosthetic limb replacement following lower limb amputation is intended to restore functional mobility and normal appearance to the amputee. The design and fitting of the socket , which provides an interface between the normal and artificial limb segments, is critical to the success or failure of a prosthesis. Recently, CAD/CAM technology for lower extremity prostheses has been used in some research centers. However, most of the socket design and fabrication require skilled craftsmanship, are labor intensive, expensive, and often require additional modification for individual fitting. . This represents a difficult and expensive clinical problem, particularly for the developing country.

RATIONAL

It was the objective of this project to develop a more efficient system using appropriate technology to design and fabricate B/K sockets and a unique therapeutic method for the residual soft tissues rehabilitation to provide good fitting. Therefore, the whole system and rehabilitation process can provide cost-effective lower limb prostheses for the amputee.

DESIGN and DEVELOPMENT

Plaster casts for the negative mold are taken from B/K residual limbs as usually. An integrated socket design and fabrication system (Figure 1), which consists of a moulding device, a vacuum forming device and a portable oven, was designed and developed. This low cost system was designed to combine several functions, including (1) the fabrication and modification of positive plaster mold of the B/K residual limb, (2)the fabrication of liners using Polyurethane between the socket and residual limb, and (3) the fabrication of socket using PVC and (4) heat treatment of the socket, during the manufacturing process. The process provides several unique techniques with low cost and efficient method to fabricate the socket and liner as well as to control the space between B/K residual limb and socket.
A tapping machine (Figure 2) was also designed and build to facilitate muscle strength and desensitize phantom pains for the stumps and associated soft tissues during the prosthesis fitting and trial. In addition to conventional therapeutic treatments, a Chinese herb intervention is also provided to enhance local blood circulation and to reduce pains and local soft tissue inflammation induced by initial socket fitting and trails on the stump. During the initial socket fitting and trail, the amputee is asked to perform walking practices several hours a day. If the prescribed socket is clinically unacceptable , additional socket rectification is made by using the method described above. Otherwise, the Chinese herb is used to improve the local soft tissue therapy after the daily socket fitting and walking trails. Most of the B/K amputee requires two weeks to obtain a functional B/K prosthesis from the initial socket fabrication until the final accomplishment of B/K prosthesis prescription

EVALUATION

Conventional clinical evaluation and subjective satisfaction are also used for assessment. Comparative evaluation using gait analysis is also planning to evaluate the socket design and prescription developed by this innovative development compared to conventional socket design and fabrication methods.

DISCUSSION

The use of the socket and liner design and fabrication system , the tapping machine and the Chinese herb intervention developed in this project has been used for more than 30 subjects with B/K amputation. All of the subjects are satisfactory with their prescribed B/K prosthesis and use the B/K socket for several years(Fig. 3 Fig 4.). The results also show clinical efficacy of using the whole integrated process for socket prescription and fitting. The fabricating systems and therapeutic intervention developed provide a cost-effective method, a simple operation methodology and a rather inexpensive way for B/K socket design, fabrication and prescription. This development can be applied directly to A/K amputation.

REFERENCE

1.Donald G. Shur, Thomas M. CIlk. Prosthetics & Orthotics. 1990,

2.Nicolas E. Walsh, M.D., Jack L. Lancaster,Ph.D., virgil W. Faulkner, C.P.O., William E. Rogers, M.S., A Computerized System to Manufacture Prostheses for Amputees in Developing Countries. J. Pros & Ortho, Vol. 1, No. 3, PP.165-181.,1989

3Albert Rappoport, MA, Gail E. Uellendahl, Ph.D., Current Trends in Prosthetics. REHAB managment Sep, 1993.

Kao-Chi Cuung, Ph.D.
Institute of Biomedical Engineering
National Cheng Keng University
No. 1, University Road Tainan, Taiwan, R.O.C.
Phone:011886-6-2757575ext63428

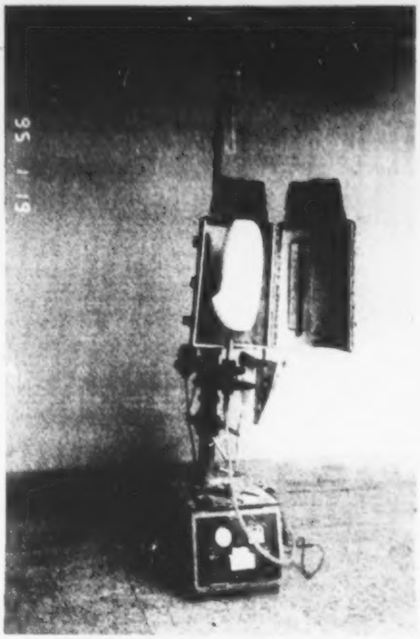


Figure 1. An integrated socket design and fabrication system

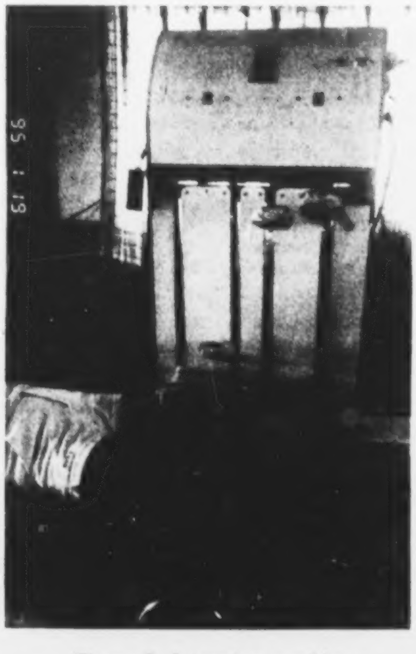


Figure 2. A tapping machine

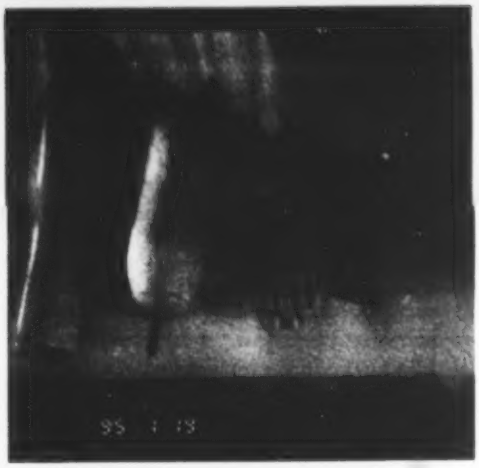


Figure 3. The component of prosthesis

Figure 4. A sample of B/K prosthesis and a user

SIG-18
Tech Act

PERSONAL ASSISTANCE SERVICES AND ASSISTIVE TECHNOLOGY: ALLIES OR ADVERSARIES

Alexandra Enders
The University of Montana, Rural Institute on Disabilities
Missoula, MT, U.S.A.

ABSTRACT

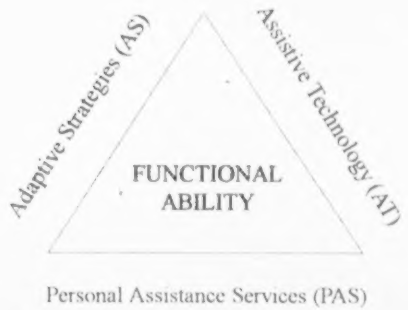
Personal assistance services (PAS) and assistive technology (AT) are integral parts of any effective support system. As funding mechanisms for both are being developed,and prioritized in policy and practice, clearer understanding is needed on how these two primary supports can be blended so they function as complimentary enhancers of functional ability. Before we debate how many resources should be allocated to each category, more discussion is needed on how the two (PAS &AT) can and should work together, and then how they can be linked in policy, practice, and payment. Without an agreed upon concept of the nature of support systems and the role and interplay of their components, advocacy effortsfor PAS and AT will continue to work at cross purposes.

BACKGROUND

When looking for assistive technology solutions, one gets into grey areas at both ends of a continuum. When looking at bathroom access, when does AT become an architectural/environmental element: is it the customized toilet stool, installing the grab rails, widening the doorway, building a roll-in shower stall? AT at the other end of the spectrum can start disappearing as adaptive strategies are developed so one no longer requires the transfer board or page turner. We can quibble over definitions and territory, but there is a lot of similarity over how "stuff" is provided and paid for; adaptive strategies are often free, though the individual may have spent a lot of time and energy working them out, or they were learned as part of therapy or through peer mentoring.

A more dynamic tension is evident when considering an individual's actual and ongoing support system. There are very few people (with or without a disability) who rely completely on technology and themselves to make their lives work. Personal assistance, whether paid or not, is a natural part of living. (If you question this, count the times in the last year you used an automotive service, took your clothes to the dry cleaners, or ate in a restaurant.) Interdependency on a personal level, and the service economy on a national and global scale, are what makes the "world go round."

SUPPORT SYSTEM ELEMENTS



STATEMENT OF THE PROBLEM

Funding for different varieties of technology "stuff" usually involves similar resource allocation strategies. There are currrently large differences however between how stuff gets paid for, and how an individual's time and services are reimbursed. Although an individual using both PAS and AT understands that the two are related and cannot really be separated, people working in the policy arena tend to forget how integrated an individual's support system needs to be. On paper, substitutability of AT for PAS may seem logical and cost effective, but in reality PAS and AT need to function together, not as discrete either-or options. Kate Seelman succinctly describes the emerging tension: "Some members of the disability community perceive assistive technology as threatening their lobbying efforts on behalf of funding for Personal Assistance services. Therefore, research is needed to determine the relationship between assistive technology and personal assistance."[1]

Research is indeed needed, but there doesn't yet appear to be any specific emphasis or support for this topic in either NIDRR or HHS, though both support AT and PAS as separate issues. At an HHS meeting in November 1994, the PAS-AT issue scored rather low in proposed priorities for research. One could be less elegant than Seelman about the PAS-AT tension, and simply state that a perception exists that there is a lot of money going into AT system change, and very little focused on PAS, so AT can take care of itself. It will be extremely dangerous and destructive to pit PAS and AT against each other as competing resources, rather than as complementary components of a support system, but that appears to be how the framework is, by default, developing.

Technology is being seen as a less expensive substitution for personal assistance services. Who hasn't written documentation for environmental control products, stating they will "reduce the need for attendant care"? There is the appealling argument of an increase in autonomy and independence acheived if a person can use an automatic leg bag opener rather than asking a person to do the chore. But who helps the individual put the device on, and who emptys the leg bag on the day the automatic widget is broken or needs cleaning or replacement? Because policy is not looking at the relationship and connectedness of PAS and AT, it is moving in the direction of encourgaging absolute either/or alternatives: either a widget or a person, not a combination, not the most appropriate at any given time or place — just pick, either the device or the person, but never both. This will be disastrous for people with disabilities, but not an unfamiliar situation. In the words of a disabled activist" We don't get what we need; if we are lucky, we may get what is gettable."[2] And since everyone depends on a combination of people and technology, if you had to choose one or the other for yourself, or perhaps for your 87 year old mother, either PAS or AT, but not both, which would you select?

APPROACH

In the 1993-94 health care reform proposals, assistive technology was included as part of a comprehensive list of personal assistance services in long term care. This relationship, AT as a component of comprehensive PAS may be worth further development, since it could lead to an integrated concept of support systems.

The 1990 National Health Interview Survey (NHIS) on Assistive Devices, reported that the "use of assistive technology devices grew more rapidly than the population during the decade", and that 52% of the people who use any assistive technologies were over 65 years of age. [3] The 1989 National Long Term Care Survey (NLTCS) reported consistent trends. "Reliance on personal assistance only declined. Dependence on equipment — by itself or in combination with personal assistance — increased." [4] Longino reports in American Demographics that ".... the use of assistive devices and housing modifications is rising sharply, while the long-term use of personal assistants alone is declining significantly. Greater residential independence, combined with the development and use of personal-assistance technologies, seem to be part of a modern elderly person's long term adaptive process. Unless there is some kind of interdependence that preserves self-respect and self-determination, dependency on family members or others will be a far less attractive alternative than technically supported self-care for those who can afford it. As the high-risk population grows .... a marketplace for assistive technology will grow with it." [5]

Resource allocation, policy decisions, and bottomline financing are driving the nature of available services. Managed care is a reality in health care in most of the US. As technology use increases, the tension between PAS and AT will increase, especially if people are forced to use equipment because that is the only reimbursable service made available, or are denied equipment and forced to use only PAS.

IMPLICATIONS

It is essential that a clear concept of the nature of support systems emerge, especially of what the purpose of the support system is. It is easier to see some of these issues in the field of aging, because they still openly admit they are trying to reduce the "burden of care", and don't bother with such euphemisms as "increasing functional independence" (If you question that independence even in the medical rehab/adult disability field still implies doing things unaided, take another look at the FIM scales.)

Recognition of the relationship between personal assistance services and assistive technology will allow us to objectively discuss mutually effective systems change strategies that will help and not hinder any individual develop a support system that is effective in multiple environments (not just at home, but at school, at work, in the community, while travelling). It may be seductive to go along with the idea of substituting widgets for people, as short sighted as that may be. But that approach is certainly not compatible with concepts such as consumer responsiveness and having control over's one's life.

Without a shared concept of support systems, one which includes both PAS and AT, advocates and policy makers will continue to work at cross purposes, arguing against each other and squandering limited systems change resources on infighting and divisive competition. Recognition of common goals, development of common strategies, presentation of shared objectives, insistence on integrated outcome measures is needed. The bottom line is that: PAS alone is down, AT use is up, AT + PAS together are up, and likely to increase. How do we work together to improve the availability of both?

DISCUSSION

It may appear that this is just more work, just one more issue to add to an already full and challenging agenda. There are several reasons why it is not additional work, and not some one else's issue; that this approach is actually part of the essence of AT systems change. Here are just three, there are many others:

(1) The issues are esssentially the same, the interval of use is different (PAS is provided on a regular schedule, AT is provided on a episodic schedule) but both variations of support services are ongoing (chronic in medical parlance) and it is in the arena of long term care, chronic disability, independent living (pick one, depending on your professional orientation) that the health care debates will rage on for years.

(2) PAS is a major issue in the disability community at all levels: nationally, regionally, state and local. People with disabilities are leading this pivotal issue in the development of community living supports. Professionals need to act in a supportive role, providing objective data, and not be perceived as working at cross purposes. PAS and AT as an essentially linked issue, provides an excellent mechanism for collaboration among advocates, as well as for challenging old assumptions about disability as a "burden of care". Advocates are building a new way of thinking about disability related support, and AT needs to be an integral part of it, not at the fringes. In all but the targeted AT discussions, AT still usually seems an add-on and afterthought. AT should not be what you do when you cannot find anything better, or when you cannot afford anything else. It is a critical building block of independent living, and needs to be incorporated integrally into the mainstream debate.

(3) There is potential for a much larger market for technology which assists caregivers, if the essential interrelationship of PAS and AT is recognized.

Technology needs to be brought into the PAS debate as an ally, not an adversary. The concept of technology providing more freedom and flexibility in the lives of people with disabilities is why many of us are in this business. Even if we did nothing beyond acknowledging support for PAS, and helping others see how these services are complimentary not conflicting or discrete, forging alliances would be a major breakthough.

REFERENCES

1. Seelman, K. "Assistive Technology Policy: A Road to Independence for Individuals with Disabilities", Journal of Social Issues, Vol.49, No.2, 1993, pp 115-136., p. 129.
2. Enders, A. and Heumann, J.,"How Adults With Disabilities Get the Everyday Technology They Need", Proceedings of ICAART 88, the 1988 RESNA Conference., Montreal, Canada, June 1988.
3. LaPlante,M., Hendershot,G., Moss,A. Assistive Technology Devices and Home Accessibility Features: Prevalence, Payment, Need, and Trends, Advance Data #217, September 16, 1992.
4. Manton,K., Corde,L., Stallard, E. "Changes in the Use of Personal Assistance and Special Equipment from 1982 to 1989: Results from the 1982 and 1989 NLTCS", Gerontologist, Vol.33, No.22, 168-176.
5. Longino, C. "Myths of an Aging America", American Demographics, August 1994, pp 36-43.

ACKNOWLEDGEMENTS

Support provided by the Department of Education, National Institute on Disability and Rehabilitation Research. MonTECH grant number H224A10002-94 and RTC:Rural grant number H133B20002-94.

Special thanks to Peter Leech and Judy Heumann who started teaching me these lessons in the 1970's at the Berkeley Center for Independent Living, and are still patiently educating me to this day. And to Irv Zola, an invaluable mentor, who will be much missed.

The triangle chart is based on Peter Leech's ideas.

Alexandra Enders, OTR/L
Rural Institute on Disabilities
52 Corbin Hall
The University of Montana
Missoula, MT, U.S.A. 59812
406/243-5467
aenders@selway.umt.edu

NORTH CAROLINA'S ADAPTIVE EQUIPMENT LOAN FINANCING PROGRAM

Lawrence H. Trachtman[1], Donna Holt[2] and Lawrence Bauer[3]
[1] N.C. Assistive Technology Project, Raleigh, NC
[2] Vocational Rehabilitation Independent Living Program, Raleigh, NC
[3] Programs for Accessible Living, Charlotte, NC

ABSTRACT

North Carolina's adaptive equipment loan financing program was initiated through a Tech Act Title II grant in September, 1992. The program operates under a loan guarantee model incorporating a public-private partnership between Programs for Accessible Living, a consumer controlled Center for Independent Living, and NationsBank, a commercial lender. Federal grant funds are used to guarantee loans made by the bank. Favorable eligibility criteria and terms are extended to consumers who may not have otherwise qualified for a loan. To date, the program has received over 400 requests for information which have resulted in 53 loan applications. Through November, 1994, 25 loans (total value $113,524) have been secured by consumers for obtaining needed assistive devices.

INTRODUCTION

Advances in commercially available assistive technologies combined with more sophisticated service delivery systems have created tremendous opportunities for improving the lives of individuals with disabilities. However, cost still remains the single greatest barrier to more people obtaining and benefiting from assistive technology. Today, numerous *funding streams* can assist the consumer or family in purchasing assistive technology. Public support may include insurance programs such as Medicare and Medicaid, legislatively based services including special education and vocational rehabilitation, and income programs such as Social Security. Private funds may include individual health insurance, disability and other private nonprofit organizations, charities and civic groups.

Even with a vast, and complicated, social net of public and private funding options, many individuals and families still must rely on limited personal funds to purchase their assistive devices. The consumer loan, while universally recognized as a purchasing strategy for mainstream society, is a model that has recently received greater attention as a funding option for individual purchase of assistive technology. Reeb (1) described in great detail the theoretical basis for assistive technology financial loan programs, including descriptions of what were then the only operating programs nationally. A few years later, Trachtman (2) presented a review of existing state and private loan program models. Since then, other loan programs have also begun operation (3, 4, 5). And just recently, the Virginia Assistive Technology System commissioned a comprehensive, critical review of the various loan program models now in operation (6). This paper presents the design and results of North Carolina's adaptive equipment financial loan program since its inception in September, 1992.

BACKGROUND

In July, 1992, Programs for Accessible Living (PAL) received notification from the U.S. Department of Education of its successful grant application "Adaptive Equipment Loan Financing Program for North Carolina Citizens with Disabilities." The grant was funded at approximately $300,000 over two years under the Technology Related Assistance for Individuals with Disabilities Act of 1988, Title II - Innovation and Demonstration Technology Grants. PAL is a private, nonprofit nonresidential Center for Independent Living located in Charlotte, N.C. PAL's partners in the application were the North Carolina Assistive Technology Project (NCATP) and the Vocational Rehabilitation Independent Living Program (VR-ILP).

PAL's successful grant application was based on the following ten unique features:

1) Based on public-private partnerships;
2) Uses available capital pool to make loans;
3) Leverages federal dollars for subsidies, interest buy-downs and guarantees;
4) Utilizes expertise of existing organizations;
5) Has substantial consumer participation;
6) Localizes services at the community level;
7) Provides for the broadest eligibility criteria;
8) Has flexible rates and terms based on ability to pay;
9) Plans early on for program continuation; and
10) Provides sufficient documentation for dissemination and replication.

The North Carolina program uses a loan guarantee model. In this model, a private lender, such as a bank, actually makes the loan using its funds which are then guaranteed by the federal grant dollars. Consumer payments help replenish the guarantee reserve, thus allowing for more possible loans. Interest on the grant funds residing in the bank also helps increase the guarantee pool. Advantages of this model include less risk for the lender and greater flexibility in setting loan eligibility criteria. Of the $300,000 grant received by PAL, approximately $220,000 were used as guarantee funds with the remaining $80,000 used for program operation (staff salary, travel, communication, etc.).

PROGRAM OPERATION

Consumer Review Board

The loan program officially began operation in September, 1992. PAL established a Consumer Review Board (CRB) to help develop program guidelines, set policies and later act as reviewing body for loan applications. Bylaws were developed which included, among other things, that the CRB consist of 11 members, at least half of whom be individuals with disabilities; the CRB meet monthly; a majority of CRB members be required for board action; and procedures for rulings and loan applicant appeals. The NCATP and VR-ILP serve as program advisors as well as helping publicize the program and providing technical assistance to potential loan applicants.

Bank Solicitation

The CRB's initial task was to identify and seek commitment from a commercial lending partner. PAL staff approached four North Carolina banks to discuss the loan program and review participation criteria. Two banks submitted written proposals and also made presentations. After critical review of the two offers, the CRB selected Charlotte-based NationsBank as the commercial lending partner for the North Carolina adaptive equipment loan program. At that time, NationsBank was the third largest bank in the U.S.

The agreement between PAL and NationsBank specifies both parties' responsibilities. PAL determines borrower eligibility, assists borrowers in completing written loan program applications, uses the CRB to approve or deny loan applications, writes an approval letter for applicants to take to NationsBank to obtain their loan, and deposits grant funds in a NationsBank account to be used as a guarantee against secured loans. NationsBank accepts loan applications from PAL-approved eligible borrowers, reviews and processes consumer credit applications (PAL-approved applicants still have to be deemed credit worthy before the CRB agrees to guarantee the loan), makes the loan to the borrower, tracks loans and provides monthly data reports, works with the CRB to resolve any problem accounts or delinquent payments, and helps publicize the program though press releases, brochures and other NationsBank information channels.

Program Guidelines

The CRB determined program eligibility as any North Carolina resident who has a disability or has a family member with a disability, *and* whose independence or quality of life would be improved by the equipment being purchased. Income limits would not be used to determine eligibility. Loan amounts were set between $500 and $15,000. The loan rate would be at a maximum of 1% above the prevailing prime rate. Loan terms could be extended by the CRB for an additional year beyond the standard term. In addition, the CRB agreed to consider loan applicants with a 50% debt to income ratio, which is higher than the bank's usual 35% to 40% ratio. And finally, the CRB would have the flexibility to use principle buy downs or other creative approaches to help loan applicants who might not qualify under the established guidelines. PAL staff, at the CRB's direction, developed the necessary forms and other materials to operate the loan program.

Loan Application Process

The following eight steps help complete the loan process:

1) Consumer or family member gets written quote for desired equipment;
2) Call or pick up PAL/NationsBank loan applications;
3) Complete loan applications, attach written quote and return to PAL;
4) NationsBank predetermines payment amount. CRB reviews loan applications monthly;
5) Approved loan applicant is referred to NationsBank;
6) NationsBank obtains credit report and assesses approved applicant's financial viability;
7) NationsBank notifies borrower and CRB of loan decision; and
8) Approved applicant follows instructions from NationsBank for obtaining their loan.

Once approved, loans can be obtained at the NationsBank branch closest to the borrower's home. All payments and other communications are then handled directly between the borrower and NationsBank. Loan applicants who are rejected, either by the CRB or NationsBank, can follow an appeal process to have their application reconsidered.

RESULTS

The North Carolina Adaptive Equipment Loan Financing Program has received over 400 requests for information since it began in January, 1993 which have resulted in 53 loan applications. Through November, 1994, 31 loans have been approved for assistive technology devices. 25 loans (total value $113,524) have actually been secured by consumers through local

NationsBank branches. (Even though the CRB approves a loan, the loan may take additional time to be processed, or the consumer may choose not to take out the loan.) The average loan amount is $4,370. Loans have been made to individuals residing in 15 different North Carolina counties; 72% are urban and 28% are rural. Eleven individuals are of Caucasian background, 6 African American, 2 Hispanic and 6 unknown. Ten individuals reported a mobility impairment, 10 a visual impairment, 3 a hearing impairment and 2 a learning or communication difficulty. Common types of loans include used automobiles and driving controls, vans and lifts, computers and computer access aids, home modifications, and reading aids for the blind. The CRB also has made two grants totaling $4,250 to enable consumers to more easily afford their loans. $123,540 remains available to continue to make guaranteed loans through NationsBank for assistive devices.

DISCUSSION

After a start-up delay due to the many operational variables that needed to be addressed simultaneously, the program has experienced great success in helping consumers and families obtain needed assistive devices. A close look at individual cases reveals the tremendous opportunities being afforded by the newly obtained equipment, including jobs, remaining independent at home or the pursuit of recreation and leisure activities. A few of the borrowers have written notes of thanks to PAL and NationsBank.

PAL obtained a no cost extension to operate the program though February, 1995. At that time, operational funds will be exhausted and PAL will continue to manage the program in-kind. Guarantee funds, however, will remain deposited with NationsBank, thus allowing for continued consumer loans. An external evaluation will be conducted at the grant's conclusion. PAL is currently seeking additional funds to staff and operate the program. A presentation was made to the Kate B. Reynolds Charitable Trust in November and PAL is awaiting word of possible funding. PAL is also considering approaching the legislature for state support of the program.

North Carolina's adaptive equipment loan program has met all of the initial criteria established in the grant application. PAL staff have responded to numerous requests on the program from other interested states. It is expected that the North Carolina program will continue for many years as a viable funding option for individuals with disabilities and their families who need assistive technology.

REFERENCES

1. Reeb, K.G. (1989). Assistive Financing for Assistive Devices: Loan Guarantees for Purchase of Products by Persons with Disabilities. Electronic Industries Foundation, Washington, DC.
2. Trachtman, L.H. (1990). Innovative and Alternative Programs for Funding Assistive Technology. Center for Rehabilitation Technology Services, Columbia, SC.
3. The Adaptive Equipment Revolving Fund: An Overview. United Cerebral Palsy of Vermont, Montpelier, VT.
4. Reid, J.E. (1994). Expanding Access to Adaptive Technology. Nevada Times, Fall 1994.
5. Loan Program offered to disabled residents. The Hartford Courant, January 22, 1994.
6. National Research of Loan Financing Practices: Model Approaches, Implementation Strategies and Funding. Prepared for Virginia Assistive Technology System by Apogee Research, Inc., September, 1993.

ACKNOWLEDGMENT

Partial support for this project was provided by the U.S. Department of Education, NIDRR, under grant number H231A20006. Mr. Wayne Dawson, former assistant director at PAL, participated extensively in the program's initial development and operation.

Lawrence H. Trachtman
North Carolina Assistive Technology Project
1110 Navaho Drive, Suite 101
Raleigh, NC 27609

SIG-19
Universal Access

BlissWrite and the BlissNet Resource Service: Resourcing Communicatively Impaired Individuals and Their Families Using Computer Mediated Communications.

Andrew McNamara and Peter H. Lindsay, Ph.D.
Blissymbolics Communication International
Toronto, Ontario, Canada

ABSTRACT

Some individuals with physical impairments are often unable to communicate through speech. Blissymbolics, a graphic representation system, offers these individuals an alternative communication system. This paper describes BlissWrite, an editor program which enables the creation of messages in Blissymbolics and traditional orthography, and a computer mediated communications network, the BlissNet Resource Service. BlissWrite is able to interface with special access software and commercially available terminal programs. The software and the service, which is staffed by nonspeaking physically disabled individuals, provides electronic mail and a variety of other services.

BACKGROUND

Many individuals who, because of physical impairments produced by conditions such as cerebral palsy, are unable to communicate through speech may begin their communication using an alternative symbol system called Blissymbolics. Blissymbolics is a simpler graphic representation than print but has many of the features of a fully structured language (e.g., grammatical markers, generative capacities). It is now widely used throughout the world as a major alternative representation system. BlissWrite is an editor program for both Macintosh and IBM computers with the capability of creating messages in both Blissymbols and traditional orthography. BlissWrite can be combined with customized access software (e.g., WiViK or Ke:nx) and standard communications software (e.g., Windows Terminal or Crosstalk for Macintosh) to produce a fully integrated computer mediated communications package. Thus, it provides, for the first time, an opportunity for Bliss users and non-Bliss users to interact with one another over a CMC network using both graphics and print.

OBJECTIVE

The objective of this project was to develop a software package and computer mediated communications network for use by communicatively impaired individuals and their families or other support persons. The computer mediated communications network provides the opportunity for a variety of activities including recreation, social interaction, tutoring, and consultation.

APPROACH

The software was originally developed under contract to the IDON Corporation, Ottawa by the Department of Communications through funding provided by the Secretary of State, Government of Canada. The objectives of this project were to produce and trial a computer-based Blissymbol "telephone" system and to develop a two-byte code as an international standard protocol for the transmission of Blissymbols. During 1992 - 1993, the software developed through and field tested within a project entitled "*Communicating, Learning, and Working with BlissNet*". This implementation and evaluation project was supported by Industry and Science Canada through the National Strategy for the Persons with Disabilities. In the fall of 1993, a proposal for upgrading the software, submitted by Blissymbolics Communication International, was approved by Industry and Science Canada (formerly Department of Communications). This software upgrade is called BlissWrite. It responds to consumer needs relating to interfacing, editing, conferencing, and menus identified in the 1992 - 1993 evaluation project and provides for the entry into worldwide telecommunications' networks through a commercial communications terminal program.

BlissWrite is a standard text editor which includes all keyboard and mouse editing abilities including all cursor key movement, and cut, copy and paste. BlissWrite has the functionality of being able to include and manipulate both Blissymbols and text within documents. Other features of the editor include the creation of new documents, permanent storage and retrieval of documents, and full printing of documents including partial printing, print preview, and print setup. BlissWrite also has the capability to retrieve Blissymbols by gloss by typing the gloss directly in the document and pressing a "hotkey". Alternatively, a search dialogue may be displayed

BEST COPY AVAILABLE

directly via the "Blissymbols" menu choice. Multiple Blissymbols may be retrieved via this dialogue in a single invocation. Online help is also available via the "Help" menu choice.

The BlissNet Resource Service, a computer mediated communications system, is a bulletin board system for Bliss and non-Bliss users. The BlissNet Resource Service is open to anyone in Ontario who has the BlissWrite software, an IBM or Macintosh computer, a terminal program, and a modem. The primary use of BlissNet-One was for interpersonal communication, although some tutoring in Blissymbolics and literacy was initiated. With the introduction of BlissWrite, the usage of this CMC system has expanded to include the following activities:
i) Expansion of BlissNet communications beyond an electronic mail service to include tutoring in Blissymbolics and traditional orthography, consultation regarding Blissymbolics and literacy, continuing education, conferencing, information dissemination, liaison with families, product and conference announcements, instructional support, and advocacy activities by and for AAC users.
ii) Vocational training for adults with speech and physical impairments who have competencies in Blissymbols and literacy, thus providing specialized job opportunities to BlissUsers to become tutors and provide other support services, e.g., display development, serving as communication partners, and advocacy.
iii) The presentation will also report on an evaluation of the applicability of the network to other language groups and other countries and to provide educational opportunities to illiterate, preliterate, and English-as-a-second-language (ESL) students based on a series of case studies.

The BlissNet Resource Service is operated primarily by Regional Trainers and Consumer Coordinators. These individuals are responsible for bringing users on-line, coordinating and providing services, and maintaining the system.

DISCUSSION

BlissWrite and the BlissNet Resource Service provide exciting, new opportunities for nonspeaking, physically disabled individuals. They have the ability to independently communicate with others. The software and telecommunications system also provide educational and employment opportunities for these individuals. Over the next two years, we hope to be able to provide an Internet connection for our users so that they may communicate with other Bliss and non-Bliss users internationally. In addition, the CMC system may have considerable use for individuals with a variety of communication problems and as a communication system for people of different languages.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Department of Communications through funding provided by the Secretary of State, Government of Canada, by Industry and Science Canada (formerly Department of Communications) through the National Strategy for the Persons with Disabilities, and the Ministry of Economic Development and Trade, Province of Ontario through the Ontario Network Infrastructure Program.

Andrew McNamara
Blissymbolics Communication International
1630 Lawrence Ave., W., Suite 104, Toronto, ON, Canada M6L 1C5
Telephone: 416-242-9114
Fax: 416-244-6543
E-mail: ae988@freenet.toronto.on.ca

BEST COPY AVAILABLE

TECHNICAL REQUIREMENTS FOR RAMPS: AN ANALYSIS OF CURRENT ACCESSIBILITY STANDARDS AND LITERATURE

Paula Guerette, Jon Sanford, Michael Jones and Molly Follette Story
Center for Universal Design, North Carolina State University

ABSTRACT

Current standards for ramp slope and length have generally been established based on performance of young, strong male wheelchair users. However, evidence suggests that current standards may not be appropriate for a wide range of older users and users with more severe functional limitations. A literature review was conducted of previous ramp evaluations and government standards to determine recommended ramp specifications, previous populations evaluated, and methodologies used to evaluate ramp performance. Findings of the literature review are presented.

BACKGROUND

It is generally accepted that a ramp is walking surface with a slope greater than (and including) 1:20; whereas a walking surface with a slope less than 1:20 is a simply a pathway. With the advent of various legislative acts such as the Americans with Disabilities Act, it is anticipated that there will be an increased reliance on ramps as a means of entrance and egress. At the same time, the validity of the existing code and standard requirements for ramps has been questioned with increasing frequency. In fact, in a recent study of fatal wheelchair accidents in the United States, 8% of accidents caused by environmental factors occurred on ramps (Calder & Kirby, 1990). With the significant change in demographics over the past two decades and the projected increase in the number of older people and people with disabilities, a reevaluation of the current ADA requirements for the design of ramps for their usability by current and anticipated populations seems appropriate. A literature review was performed to establish the appropriateness of a reevaluation of ramp standards with a wider range of individuals. The major findings of the literature review are presented.

RESEARCH QUESTIONS

- What is the existing research on ramp slope, length and landings?
- What are the potential problems with current ramp specifications?
- What are the methodologies that have been used for ramp evaluation ?

METHOD

A comprehensive search of all possible information sources related to ramp slope, length and landings was conducted. The search focused on four types of information sources: 1) electronic databases and bibliographical indices of periodicals; 2) published materials (books and periodicals); 3) proprietary reports/guidelines/protocols identified through professional contacts including the Advisory Panel members; and 4) literature on products and technologies related to ramps, stairs, emergency egress, and resistance research. The search focused primarily on human factors/ergonomic issues, human subject testing, methods and the four demographic variables (age, gender, type of impairment, and type of mobility device) that were used to determine the appropriate populations to evaluate.

RESULTS

Slope and Rise. ADAAG, ANSI, and UFAS all permit a maximum rise of 30 inches for each ramp run. The three differ, however, in their treatment of slope, rise, and run as variables. Both ADAAG and UFAS assume that only run is a variable, whereas ANSI suggests that slope and run are both variables, with restrictions in one often compensated by the other. As a result, ADAAG and UFAS allow a maximum run of 40 feet for slopes between 1:16 and 1:20, ANSI permits ramps with a slope of 1:20 to have a maximum run of 50 feet. Despite the general concurrence among the codes related to slope, rise, and run, research suggests that the maximum rise of 30 inches between landings (which would result in a 30 foot ramp length at the recommended 1:12 gradient) may be excessive. However, because prior studies have been conducted with different populations, consensus is lacking regarding the optimum ramp run.

BEST COPY AVAILABLE

Clear Width. Although federal standards are uniform in requiring ramps to be at least 36 inches wide, none specifies how clear width is to be measured. ADAAG describes "clear" as being "unobstructed," although unobstructed may vary between people who are ambulatory and those who use wheelchairs.

The 36 inch dimension is consistent with the minimum required width of an accessible route. However, a number of states require access ramps to be between 44 to 48 inches in order to be consistent with egress ramp requirements in the model building codes for buildings with occupancies of 50 (or more) persons. Although the 44 to 48 inch dimension would permit an ambulatory person and a person using a wheelchair to pass each other, prior research by the Center for Accessible Housing indicates that in facilities in which there are a number of people who use wheelchairs (i.e., more than 1 or 2), wider ramps may be appropriate to accommodate two-way wheelchair traffic on the ramp.

Landings. The federal standards and model codes require the width of landings on a straight run ramp to be as wide as the ramp run leading to it (a minimum of 36 inches), or as wide as the widest ramp run leading to it. Where a ramp changes direction, most standards and codes require a 60 inch by 60 inch landing. Templer, et al. (1982) recommended that a minimum landing distance of 66 inches at the top and bottom of a ramp was necessary to allow adequate stopping distance for 85% of those descending the ramp and for 91% of those ascending the ramp. Travers (1991) recommended that rest platforms at least 71 inches x 71 inches be located at the top of a ramp.

Handrails. All of the codes and standards require handrails on ramps that have a slope greater than 1:20, except Kentucky which only requires handrail on ramps with slopes less than 1:15. The location for handrails is generally along both sides of ramp segments, except in several states (e.g., North Carolina) which consider handrails as a function of ramp slope and the slope or drop off of adjacent terrain in determining railing locations. Travers (1991) recommends that handrails should be provided at least on the outer edge of the ramp, and preferably on both sides, in order to allow ambulant people with mobility limitations to negotiate the ramp. The height of handrail requirements varies from 30 to 38 inches. ADAAG, UFAS and ANSI suggest the use of a second handrail at a lower height for facilities where children are the primary users.

Cross Slope. Maximum cross-slope varies between 1:48 and 1:50, although several codes do not have a provision for cross-slope along a ramp. In terms of usability, the difference between a cross-slope of 1:48 and 1:50 is probably negligible. Several articles addressed the issue of cross slope, although none evaluated cross slopes that were consistent with the code requirements. For example, Brubaker et al. (1986) found that a 2o (1:29) side slope adversely affected a wheelchair user's ability to traverse a ramp. A second source, Travers (1991) noted that the cross fall should not exceed 1:100 in order to allow the wheelchair user to maintain control.

Surfaces. The codes and standards are fairly uniform in their specification for "stable, firm and slip-resistant" surfaces. ADAAG is the most explicit, recommending a static coefficient of friction of 0.8 for ramps. The findings of several studies that evaluated ramp surfaces clearly indicate that ramp surfaces can affect performance. Walter (1971) found that the degree of friction between the ramp and the wheelchair tires significantly affected the amount of effort required to ascend the ramps. A second study, Sweeney et al. (1989a) found that appropriate surface finishes are dependent on the type of user. They found that self-propelling wheelchair users preferred a rough surface in order to maximize traction and facilitate safety on the ramp. In contrast, attendants who propelled wheelchairs preferred a smoother surface in order to facilitate wheelchair movement.

DISCUSSION

The literature review revealed significant and interesting findings about the populations previously tested and methodologies used. In addition, despite the general agreement among the major codes and standards, as well as the state codes, there are a number of areas in which unique provisions in some of the state and model codes as well as findings from research studies that indicate that changes to ADAAG may be warranted.

First, studies of ramp performance were evaluated in terms of the degree to which they have addressed ramp negotiation with a wide variety of mobility impairments over a wide age range. Most studies, however, used fairly homogeneous populations both in terms of age and ability. As a consequence, recommended gradients were found to vary widely, and seem to be associated with several factors related to the population evaluated. These factors include degree of mobility (i.e., nonambulatory individuals who use self-propelled, attendant-propelled, or powered wheelchairs or ambulatory individuals who walk with difficulty and/or use assistive walking devices) and amount of stamina. For example, both Elmer (1957) and Canale, Felici, Marchetti & Ricci (1991) recommended fairly steep ramp slopes (up to 1:6 and 1:6.7, respectively) based on younger samples with good upper body strength who were able to propel their own wheelchairs fairly easily. Steinfeld, Shroeder & Bishop (1979), on the other hand, concluded that ramp slope should vary between 1:16 and 1:20 based on a sample of individuals with more restricted functional abilities and a wider range of ages.

Second, performance variables and procedures used to measure them varied across studies. Studies included a number of objective performance measures such as time required to traverse a ramp, maximum distance attained, distance between stops, number of strokes made on the wheelchair rim (for independent wheelchair users), and number of steps taken (for attendant-propelled wheelchair users and those using assistive walking devices) as well as subjective measures such as asking participants to stop when they needed to rest (e.g., Templer, et al., 1982). Interestingly, however, most studies that have evaluated energy expenditure of people who use wheelchairs and assistive devices (which could be a critical factor in an individual's ability to traverse a ramp) have done so on level surfaces.

Finally, based on this analysis, a number of changes to ADAAG should be considered. These include: ensuring that slope does not exceed 1:12 over short distances of a ramp; reducing the maximum rise in new construction and alterations; increasing the clear width of ramps to meet provisions for egress, thus permitting ramps to function as an accessible means of egress and by multiple individuals in wheelchairs; increasing the size of landings; clarifying the provision for height of handrails; reducing the maximum permissible cross slope; specifying maximum heights for walls, railing, or projecting surfaces used as guardrails; and protecting exterior ramps in cold climates.

REFERENCES

Brubaker, C.E., McLaurin, C.A., and McClay, I.S. (1986). Effects of slide slope on wheelchair performance. Journal of Rehabilitation Research and Development, 23(2), 55-58.

Calder, C. J., and Kirby, R. L. (1990). Fatal wheelchair-related accidents in the United States. American Journal of Physical Medicine and Rehabilitation, 69(4), 184-190.

Canale, I., Felici, F., Marchetti, M. and Ricci, B. (1991). Ramp length/grade prescriptions for wheelchair dependent individuals. Paraplegia, 29, 479-485.

Elmer, C. D. (1957). A study to determine the specifications of wheelchair ramps. Unpublished masters thesis. University of Iowa.

Steinfeld, E., Schroeder, S. and Bishop, M. (1979). Accessible Buildings for People with Walking and Reaching Limitations. Washington, DC: US Department of Housing and Urban Development, US Government Printing Office.

Sweeney, G.M., Harrison, R.A., and Clarke, A.K. (1989). Portable ramps for wheelchair users--an appraisal. International Disability Studies, 11(2), 68-70.

Templer, J.A., Wineman, J., Zimring, C.M. (1984). Guidelines for accommdating the handicapped on crossings: final report. Federal Highway Administrations.

Travers, A.F. (1991) Ramps and rails. BMJ, 302(6782), 951-954.

Walter, F. (1971). Four architectural movement studies for the wheelchair and ambulant disabled. Part 3--ramp gradients. London: Disabled Living Foundation.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Architectural and Transportation Barriers Compliance Board.

Paula Guerette, Ph.D.
Dept. of Internal Medicine & Gerontology
The Bowman Gray School of Medicine
Medical Center Boulevard
Winston-Salem, NC 27257

TECHNICAL REQUIREMENTS FOR RAMPS: HUMAN SUBJECTS TESTING

Molly Follette Story, Michael L. Jones, Jon A. Sanford, Paula Guerette
Center for Universal Design, North Carolina State University

ABSTRACT

This paper describes the human subjects testing portion of a project sponsored by the Architectural and Transportation Barriers Compliance Board to evaluate the usability of ramps of differing slopes and lengths allowed the ADA accessibility guidelines. Testing included participants of all ages using every type of mobility aid: canes, crutches, prosthetics, wheelchairs, scooters, etc. Each participant was asked to traverse six different ramp slopes, both up and down, and provide feedback on how difficult each trial was. The researchers measured each participant's pulse rate, the amount of time it took to climb each ramp, and the location and duration of rest stops.

BACKGROUND

The Architectural and Transportation Barriers Compliance Board (Access Board) funded a study to evaluate the usability of ramps of differing slopes and lengths for user groups that were underrepresented in previous studies of ramp slope. Based on a literature review to determine results of previous studies (Task 1) and a population study to determine representative user groups to be tested (Task 2), Task 3 of the project was to conduct human subjects testing.

RESEARCH QUESTIONS

This study attempted to answer several questions about the ease of use of various ramp slopes and lengths. What is the maximum ramp slope? What is the optimal slope? What are the maximum and optimal ramp lengths? What is the relationship between ramp slope and length? For people with what types of mobility impairments are these slopes and lengths appropriate, and does it vary by disability?

METHOD

Participants. On the basis of the information provided by the population study, a sampling frame was established that included individuals of varying ages who use different types of mobility aids. Six groupings were established based on functional differences by these age groupings in performance on ramps. In addition, eight categories of type of mobility aid used were established: manual wheelchairs; two categories of power devices (wheelchairs and scooters); two categories of mobility aids (canes or crutches, and walkers); prostheses; orthoses; and no mobility aid but activity limitation.

Participants for testing were enlisted through existing networks established by researchers in the Raleigh-Durham area of North Carolina. These networks included advocacy groups and agencies, human services agencies, rehabilitation programs and providers and non-profit agencies operating residential programs for people with disabilities. The two avenues of solicitation that proved to be most successful at generating volunteers were advertisements in local newspapers and personal references from previous participants.

All potential participants in the study were interviewed by telephone prior to setting up an appointment. This procedure assured that individuals fit into an empty cell of the testing matrix and allowed researchers to conduct a medical prescreening. Permission from subjects' personal physicians was obtained for any participant with a history of heart disease, pulmonary disease, diabetes, or any other active or recent condition of concern to the interviewer.

Apparatus. The 30 ft. aluminum ramp consisted of three 3 ft. by 10 ft. sections with a triple row of tubular aluminum side railings (at 8, 21.5, and 34 in. above the ramp surface). A 5 ft. entry ramp connected to a 4 ft. level landing was located at the starting point on the ramp. The top end of the ramp was connected to a 5 ft. by 8 ft. aluminum terminal landing fitted with a triple row of tubular aluminum side railings.

The ramp was adjustable to seven calibrated slopes: level, 1:20, 1:16, 1:14, 1:12, 1:10 and 1:8. Two manually-operated winches adjusted the height of the ramp. The terminal landing height was controlled by two additional winches. The ramp and platform were supported by horizontal pipe beams, the collars of which rested on hitch pins passing through the vertical support poles at predrilled heights.

In order to facilitate data collection, the ramp surface was marked with 1/2 in. vinyl tape across the entire width of the ramp at 6 in. intervals and labeled in one foot increments, from "0" to "30" along either side of the ramp.

Research Staff. At a minimum, three staff were present at each test session: one to record trial data, one to serve as a spotter for the subject and monitor pulse and blood oxygen saturation (measures of physical exertion), and one to videotape the session. A fourth staff person was present during most sessions to serve as a second observer in order to assess inter-observer reliability.

Independent and Dependent Variables. The primary independent variable was the slope of the ramp for each successive trial. At the beginning of each session, the subject was asked to traverse the ramp in two directions, with the ramp in the level position. All dependent variables were measured during these trials, which served as a baseline for comparison to subsequent trials. After this baseline run, the ramp slope was varied in a random order for six pairs of additional trials. The variable slopes were 1:8, 1:10, 1:12, 1:14, 1:16 and 1:20. Both an ascending and a descending trial was conducted at each slope. In every case, subjects were instructed to proceed up or down the ramp in the manner and at the pace that they would normally proceed.

Seven dependent variables were documented for each ramp trial. They were: total distance; total time; number, duration and location of rest stops; pulse and oxygen saturation; control of speed and occurrences of slipping, etc.; need for assistance; and the participant's ratings of trial difficulty.

1. *Total Distance* was a measure of the farthest distance traveled on the ramp. If the subject was not able to traverse the entire ramp, the total distance was determined by identifying the subject's stopping point. The stopping point was defined as the last 6-inch interval crossed by the subject's following foot or the rear-most wheel of his/her wheelchair or scooter. Total distance was calculated as the distance from the starting to the stopping point.

2. *Total Time* was a measure of the elapsed time from the instant the subject crossed the starting point to the instant the stopping point was identified. Observers stopped timing when: a) the subject traversed the entire ramp or b) the stopping point was identified before the subject traversed the entire ramp.

3. *Number, Duration and Location of Rest Stops* were noted for each trial. Subjects were allowed to take up to two rest stops during the trial. Each rest stop could last up to 15 minutes. Each time the subject made a rest stop both the location and duration of the stop were recorded. The location was determined as the last 6-inch interval crossed by the subject's following foot or the rear-most wheel of his/her wheelchair or scooter. The duration was defined as the elapsed time from the instant forward motion ceased for five seconds until forward motion was resumed, rounded to the nearest second.

4. *Pulse and Oxygen Saturation* were documented at the beginning and ending of each trial. Changes in subjects' pulse and blood oxygen saturation from the beginning to the end of each trial were assessed as a quantifiable measure of exertion. These measures were obtained using a surface electrode (reflectance oxisensor, Nellcor model RS10) placed on the subject's forehead and held in place with a cotton elastic headband. Both measures were electronically collected using a portable pulse oximeter (Nellcor model N20).

5. *Control of Speed and Occurrences of Slipping, etc.* were noted anecdotally by observers judging the subject's ability to control their speed of ascent and descent of the ramp. Indications of problems controlling speed included collisions with spotters or the side railings, faltering due to too little speed, and hesitant descents. Any slips, stumbles, or skids were

also documented. The location and elapsed time since the start of the trial were noted for each episode.

6. *Any Need for Assistance* given to the subject (physical support; use of the restraint tether) was recorded and the subject's location on the ramp at the time was also noted.

7. *Participant's Ratings of Trial Difficulty* were obtained from the subject after completing each trial. The participant was asked to rate the difficulty of the ramp on a graphic scale.

Observation Technique. For trials in which inter-observer reliability was assessed, two observers were stationed across from each other on opposite sides of the ramp directly in line with the subject. They simultaneously observed and independently recorded subject's performance data during each trial. The observers each used a Newton Message Pad 110, programmed for data entry of events as they occurred.

RESULTS

To date 111 of the sample of 192 subjects have been tested. Subjects ranged in age from 35 to 74 years and represented a range of disability types.

Preliminary results indicate that most participants were able to traverse all six slopes in both directions, ascending and descending. However, data also indicate that although the slopes are usable, steeper slopes increased time taken to traverse the ramp, caused pulse rates to climb and oxygen saturation levels to drop among some subjects. It also appears that shallower slopes of 1:14, 1:16 and 1:20 are easier for most people. Finally, ambulatory participants indicated that walking down the ramp was often more difficult than going up, because it was harder on their knees and they were more concerned about the possibility of falling.

DISCUSSION

Preliminary results indicate that when other variables that could impact ramp use (e.g. side slope, lengthwise slope, surface texture and environmental conditions) are controlled, the 1:12 maximum slope currently allowed by access codes seems to be usable by most individuals. In addition, some individuals stated that they preferred steeper, but shorter ramps because traversing any slope was difficult and they would rather "get it over with." However, because approximately 70% of the 74+ subgroup remains to be tested, it is anticipated that usability data, at least for that subgroup, may be impacted.

People who used walkers were especially uncomfortable going down the ramp, particularly on steeper slopes. In descent, the base of the walker was closer to a person's feet and the top was tilted away from the body. The increased distance between the top of the walker and the subject's body, caused the walker to be at a lower height and forced subjects to lean forward when they moved the walker ahead. This often caused great discomfort, especially on the steeper slopes.

Finally, it is important to acknowledge that the test ramp is unlike those normally encountered in the real world. It has no side slope, the surface has a uniform lengthwise slope and a regular texture, and it has a hand rail on each side with horizontal members at three different heights. In addition, lighting is good and climate is controlled. There are no environmental problems such as adverse weather conditions to complicate the task of negotiating the ramp. The presence of a spotter and two or three observers has an inevitable effect on participants as well, sometimes causing them to feel pressure to perform even though this was not encouraged. All of these factors are inevitable in research, but their effects on the results obtained need to be taken into consideration. More research is definitely indicated on the subjects of surface finish, handrail location(s) and height(s), and ways to make ramps easier to use in ice and snow.

ACKNOWLEDGMENTS

Funding for this project was provided by the Architectural and Transportation Barriers Compliance Board.

Molly Follette Story
Center for Universal Design
North Carolina State University
Box 8613
Raleigh, NC 27695-8613

MOBILE HOMES AS AN AFFORDABLE ACCESSIBLE HOUSING OPTION FOR RURAL INDIVIDUALS WITH DISABILITIES

Bettye Rose Connell, Ph.D., and Brad Bernier, BA
Center for Accessible Housing, North Carolina State University, Raleigh, NC
Center on Rural Rehabilitation Services, University of Montana, Missoula, MT

ABSTRACT

Mobile homes are a widely recognized form of affordable housing, and a form that is widely adopted in rural areas. However, few mobile homes are designed in such a way that they are intrinsically accessible (i.e., universally designed). This paper reports the results of an exploratory study conducted with individuals with disabilities who live in rural communities to examine mobile homes as affordable, accessible rural housing options. Results of the study will be disseminated to the mobile home industry, and guidelines for selecting and modifying mobile homes will be distributed to provider groups serving rural clients.

BACKGROUND

Mobile homes are a familiar type of rural housing. Over 80% of all mobile homes are located in rural areas (Geisler & Mitsuda, 1987). During the 1980's, this type of housing grew from 10.4% to nearly 16% of all rural housing stock (Ghelfi, 1993). In a recent national survey of adults with disabilities living in rural areas, 12% reported living in and being satisfied with owner-occupied mobile homes (Seekins, Jackson, & Dingman, 1991).

The Manufactured Housing Institute (1991) reports that 18% of all new mobile home buyers in 1991 earned less than $10,000 annually, and that the median income of all new buyers was $21,900. Housing affordability is a key concern for many people living in rural areas, including but not limited to people with disabilities. Adults with disabilities living in rural areas have rated "(not) having enough to get by" as one of the major problems they face (Seekins, et al., 1991).

Prior research suggests that minimum accessibility enables an individual to enter and exit the home, move around the home, and toilet (Sanford, Tector, Donovan, & Humkey, 1992). Although a number of manufacturers offer units that can be ordered with factory-installed accessible features, few offer universally-designed units. Existing units that are not universally-designed and readily adaptable may present particular problems for those who purchase or rent used units which they plan to modify.

RESEARCH QUESTIONS

1. Are mobile homes affordable for rural people with disabilities? What obstacles do these individuals encounter in qualifying for loans, making down payments, meeting monthly loan/rent payments, and paying for other routine costs?

2. What accessibility modifications are typically made? Are typical modifications adequate? Who makes accessibility modifications? Are there barriers to achieving accessibility in mobile homes?

APPROACH

Study participants included individuals who lived in a mobile home, resided in a rural area, and whose households included one or more persons) with a permanent disability, regardless of etiology (e.g., age-related, result of accidental injury) that impacts balance, mobility, or reach. During the study the last criterion was modified to include individuals with multiple chemical sensitivities who had expressed interest in participating.

Staff of Independent living Centers, state Divisions of Vocational Rehabilitation, Area Agencies on Aging, and other rehabilitation professionals in ten states were contacted to solicit their assistance in identifying and recruiting study participants. Because many of the cooperating professionals were drawing from confidential client lists, they typically contacted a potential participant and secured their permission to release his/her name to the study project staff for follow-up. Potential participants were contacted by telephone to verify their eligibility and secure their agreement to participate in the telephone interview portion of the study. This process yielded a sample of twenty-eight households in 10 states with one or more adults with a disability in the household. These individuals completed a 30-minute interview. At the end of the interview, they were asked if they would participate in the site visit portion of the study. Most agreed to do so. A total of 28 interviews and 5 site visits were completed.

The telephone interview instrument was adopted from an existing mail questionnaire that has been used to obtain general information from the 1400$^+$ members of a national Design Advisory Network about their disability, housing characteristics including accessibility, and socio-demographic characteristics. Questions were added about financing housing purchases and how modifications were obtained. The site visit protocol was adopted from one used to document and evaluate housing accessibility (Connell and Sanford, forthcoming). It entails participants demonstrating and/or describing routine activities and

609

how the design of task-relevant aspects of their housing helps or hinders task performance.

RESULTS

The respondents were nearly equally divided between men (46%) and women (54%). Thirty-nine percent of the respondents lived alone. Respondents ranged in age from 30 to 75 years old. Two households included a parent with a disability and an 8 year old child with a disability; a third household included two adults with a disability. Although adult respondents varied widely in the number of years they had been disabled (1 to 51 years), half had been disabled 9 or fewer years (mean = 12 years). Of those reporting their annual income, 42% had a household income of $10,000 or less, and 42% had a household income of $10,001 to $20,000.

The respondents included nonambulatory individuals as well as ambulatory and partially ambulatory individuals. A third group of respondents reported disability due to multiple chemical sensitivities (MCS). Respondents used a variety of mobility devices including power and manual wheelchairs, crutches, canes, braces, walkers, and scooters. Some respondents used more than one mobility device. Manual wheelchairs were the most widely used device (25% of respondents).

Some respondents had lived in their home for 15 or more years. However, most had a much shorter length of residency (mean = 5.5 years, median = 3.5 years). Respondents lived in older units; 29% of the homes were over 20 years old, 32% were 11 to 20 years old, 14% were 6 to 10 years old, and 18% were 1 to 5 years old. A large number of the respondents (79%) purchased or rented used units .

The large majority of the respondents owned their home (90%). Of those who owned their home, 42% bought it outright. Reported cash prices ranged from $3,000 to $18,000. Savings, insurance settlements, and funds from the sale of prior residences were used for cash purchases. Of those who financed their home purchases, 24% reported arranging their loan through a bank, 24% through seller financing, and 18% through a finance company. In general, recently disabled individuals often had insurance settlements and recent employment histories (even if unemployed at the time) that limited the obstacles they experienced in arranging a loan. On-going costs, such as monthly payments and annual maintenance costs, were problems for respondents irrespective of length of disability. Most respondents reported they could not afford insurance for their homes.

Most respondents' homes were single-wide units (70%) and had one or two bedrooms (64%). Among respondents with mobility impairments, the greatest number of modifications had been made to entry areas and bathrooms. Over half (56%) had ramps. Less than 40% of the respondents with mobility impairments indicated that there was adequate maneuvering space to enter rooms. About half of the respondents with mobility impairments had toilet (48%) and tub/shower (52%) grab bars. Far fewer (26%) reported adequate clear floor space in front of the toilet or tub.

The interviews documented the presence/absence of an inventory of accessible features and modifications commonly adopted by people with mobility impairments. The site visits provided insights about how well existing modifications and unmodified features worked. (The site visit participants included three individuals who used power or manual wheelchairs, one who used a scooter, and one who used a walker and a wheelchair.)

Ramps observed during the site visits often exceeded conventional ramp slope (1:12). The observed ramp slopes were the result of the typical location of an existing entry door wide enough to accommodate a wheelchair (usually on the side of the unit at a sliding glass door), the height off the ground of the floor level at the entry door, the desirable ground level end point of the ramp, and the available space on the side of the unit for the ramp, landings and switch backs. The floor level of homes was often the equivalent of 4 or more steps off the ground, necessitating ramps that were too long for the available space or too steep for easy and safe use. A number of ramps were observed with top landings not level with the interior floor, probably reflecting contractors' lack of experience in building ramps, and with sliding glass door tracks preventing an unobstructed transition between the interior and landing.

Most interior doors were not wide enough to accommodate a wheelchair, and the ability to widen doors was related to their placement in the wall; those placed close to intersecting walls could not be widened or not widened enough. Similarly, hallways, particularly those with 'jogs' were very narrow for wheelchair users. Making right-angle turns from hallways into rooms was particularly difficult. Some participants had removed hall closets and dismantled other walls to create minimal turning space. This often left unsightly gaps in floor and ceiling finishes. These problems were exacerbated in mobile homes with floorplans that provided access to bedrooms via hallways rather than direct access from a central space such as a family room.

The most extensive problems were in bathrooms. Limited floor space made it difficult to position a wheelchair to transfer to the toilet or use the lavatory. Although the 'footprints' of bathrooms were larger than expected, often they were not large enough to readily allow relocating fixtures or installation of different types of fixtures to improve layout for individuals with disabilities. The widespread use of "garden tubs," with wider than usual side walls and a cutaway with a step at the midpoint of the side, made transferring difficult and unsafe.

Respondents with MCS reported modifications that reduced exposure to materials and the by-products of building systems which caused adverse effects. This typically required gutting or sealing existing interiors to eliminate problem materials and systems (e.g., carpet, particle board, PVC pipe, gas heating systems), and rebuilding interiors and replacing systems (e.g., copper plumbing, electric heating).

The few respondents with mobility impairments who purchased new homes ordered them with factory-installed accessibility options. However, service agencies (ILCs, Voc Rehab, local aging services), local jobs programs, and special interest groups (MS Society) were the most frequently reported (48%) means of obtaining modifications, particularly for used mobile homes. Respondents with MCS and their families implemented most of their modifications. There was little reliance on manufacturers, contractors, or local programs.

DISCUSSION

Although this exploratory study is limited by the size and heterogeneity of the sample, the results are suggestive of a number of issues that are potentially important to the viability of mobile homes as an affordable, accessible rural housing option. Overall, the low cost of mobile homes, particularly of used units, make them affordable for many low income households that would have difficulty in securing housing in rural areas where other forms of low cost housing are limited. For individuals with disabilities living in rural areas, affordability may be more basic than accessibility. However, affordability may be relative even among individuals with disabilities. It appears that respondents with mobility impairments who were recently disabled had a one-time cash reserve that had be used to obtain housing. Although cost was an issue, they were able to use their cash to leverage favorable financing, if not purchase a unit outright. In contrast, respondents with mobility impairments who had been disabled for a longer period of time and had limited income and savings appear to have had fewer affordable options and greater difficulty in arranging financing for units that were affordable. The individuals with multiple chemical sensibilities often had been moving around the country, first looking for a geographic location they could tolerate, and then seeking housing they could afford. A key issue in housing affordability for this group included not only the price of the unit, but also the cost of gutting and replacing or conditioning all materials and systems.

Despite some apparent financial advantages among recently the disabled individuals, this did not ensure that they obtained accessible or readily adaptable housing. As a group, these individuals had limited experience living independently as a person with a disability, limited insight about how their functional capabilities translated into the amount and type of space that would work for them, and often were in a hurry to make a decision. Several individuals in this group reported that these personal factors resulted in them purchasing homes that they have since discovered do not meet their needs as well as they had expected. This situation points to a likely gap in information resources.

Finally, mobile home manufacturers are increasingly offering accessible models and introducing universally designed model lines. However, the results of this study suggest that new units may not be affordable to many individuals with disabilities, and more affordable older units appear to vary widely in terms of the feasibility of modifications. There is a need to provide consumers and service delivery professionals with information that assists them in identifying used units that lend themselves to modification.

REFERENCES

Connell, B.R. and Sanford, J. (forthcoming). "Housing Needs of Older People to Facilitate Independence and Safety." In Hyde, J. and S. Lansprey, (eds.) *Staying Put: Changing the Place Not the People*. Butterworth Press.

Geisler, C., and Mitsuda, H. (1987). Mobile-home growth, regulation, and discrimination in upstate New York. *Rural Sociology, 52*(4), 532-543.

Ghelfi, L.M. (1993). Mobile homes have been the largest source of growth in nonmetro homeownership for two decades. *Rural Conditions and Trends*, Fall, 60-61.

Manufactured Housing Institute. (1991). *Quick Facts*. MHI, Arlington, VA.

Sanford, J., Tector, J., Donovan, M., and Humkey, C. (1992). Final Housing Inventory Protocol for the Mass. Rehabilitation Commission.

ACKNOWLEDGMENTS

This project was supported by funding from the National Institute for Disability and Rehabilitation Research, grant numbers #H133B20002-94 and #H133B90003.

Bettye Rose Connell, Ph.D.
Center for Accessible Housing
Box 8613 NCSU
Raleigh, NC 27695-8613

611

DESIGN AND DEVELOPMENT OF NEW TOILET FIXTURES TO MEET THE NEEDS OF DISABLED AND ELDERY PEOPLE.

Pascal Malassigné, MID, IDSA, Mark Cors, BFA, Todd Hoehn, BFA.
Clement J. Zablocki VAMC, Milwaukee, WI.
Milwaukee Institute of Art & Design, Milwaukee, WI.

ABSTRACT

This paper reports the findings of a VA Rehabilitation R&D Service sponsored project for which new toilet prototypes were designed and developed to foster safer and more independent toileting among older individuals and people with disabilities. The prototypes included two new toilets with integral grab bars and hand holds and three toilet inserts with integral hand holds.

Following design and development an evaluation phase of these prototypes with sixty-eight participants was undertaken with videotaping of simulated toileting activities on the prototypes (i.e., getting on and off the toilet) as well as on a standard, accessible toilet. Expert assessment of participant performance and analysis of pre and post-trial self report data were used to evaluate the degree of independence and safety associated with each design. Based on the results of the evaluation, recommendations for the final design of the fixtures will be made.

BACKGROUND

This study is one in a series of projects concerned with the ability of older and disabled people to carry out routine daily activities safely and independently. Difficulty in toileting independently is common among non ambulatory disabled and elderly individuals who have difficulty transferring. Similarly ambulatory individuals with age related impairments such as arthritis, have difficulty sitting and standing.

In response to these problems, the investigators designed and evaluated several new toilets for use by non-ambulatory people and three toilet inserts with integrated hand holds to be used by ambulatory and non-ambulatory people. The insert were designed to replace existing raised toilet seats that have been found to be unsafe by users.

RESEARCH QUESTIONS

The following questions were examined during the design development activities:

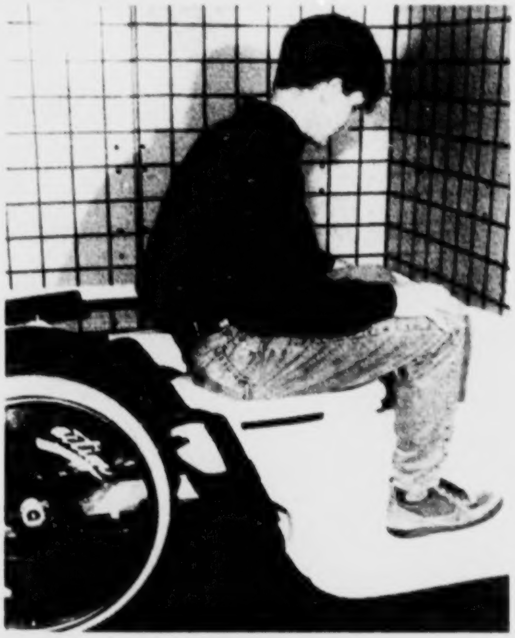
1. Do different prototype designs result in differences in the difficulty, safety and independence of toileting activities?

2. Are there age and disability-related differences in the safety and independence in toileting associated with different toilet designs?

PROTOTYPE DESIGNS

Straddle toilet

- The straddle toilet is a floor or wall mounted fixture, with surrounding grab bars to assist in transferring. The straddle toilet has an opening on each side to facilitate digital stimulation.
- Intended users: paraplegics or any other users who can transfer from a wheelchair to a toilet for bowel care. Quadriplegics or other users who do their bowel program from a bowel care-shower chair.
- Access: The user positions his/her wheelchair in front of the straddle toilet, then slides over the toilet with the use of grab bars. Access from a bowel care-shower chair by rolling over the toilet.



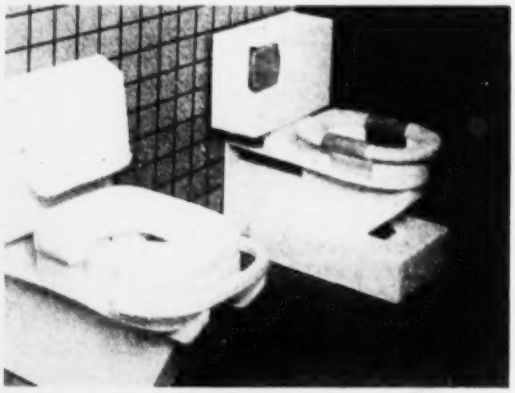
Straddle toilet

612

DESIGN OF NEW TOILET FIXTURES

Toilets with passive assistance

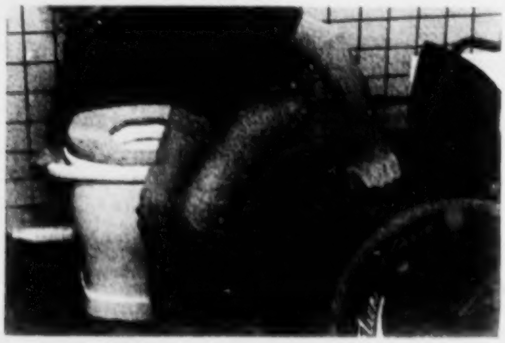
- The toilets with passive assistance are floor or wall mounted fixtures, with surrounding hand holds to assist in patient transfer. The fixture have an opening on each side to facilitate digital stimulation.
- Intended users: paraplegics or any other users who can transfer from a wheelchair to a toilet for bowel care.
- Access: The user positions his/her wheelchair sideways or perpendicularly to the toilet. The user grasps the built-in hand holds to transfer.



Toilets with passive assistance

Toilet insert with side handles

- The insert with side handles is a floor mounted fixture designed to go over a toilet. The insert can be attached to the bolts of the toilet and has an optional footrest for additional stability.
- Intended users: ambulatory and non-ambulatory individuals who transfer from a wheelchair to a toilet for bowel care.
- Access: walking approach and wheelchair approaches from the side, at an angle or from a perpendicular position.



Toilet insert with side handles

Toilet insert with recessed handles

- The insert with recessed handles is a floor mounted fixture designed to go over a toilet. The insert can be attached to the bolts of the toilet and has an optional footrest for additional stability.
- Intended users: ambulatory and non-ambulatory individuals who transfer from a wheelchair to a toilet for bowel care.
- Access: walking approach and wheelchair approaches from the side, at an angle or from a perpendicular position.

Toilet insert with vertical handles

- The toilet insert with vertical handles is a floor mounted fixture designed to go over a toilet. The insert can be attached to the bolts of the toilet and has an optional footrest for additional stability.
- Intended user: ambulatory patients.
- Access Walking approach, using handles to assist in sitting and rising.

EVALUATION OF PROTOTYPES

The evaluation of prototypes included four tasks: (1) adapt a portable toilet room mock-up used in previous research (Sanford and Megrew, 1994, 1995); (2) conduct pre-trial interviews; (3) complete the test trials; and (4) conduct post-trial interviews.

A full scale, transportable toilet room mock-up consisting of two walls at right angles of 244 x 182 cm -72" x 96" was used for this evaluation. The mock-up included accommodations for the straddle toilet, a standard height toilet with the seat at 35.5 cm - 14" over which the inserts could be placed, and two video cameras to record the test trials.

The sample consisted of sixty eight individuals. The straddle toilet, which is intended for individuals who transfer to a toilet from a wheelchair or who use a bowel care chair was evaluated by non-ambulatory participants only.

The insert with vertical handles, which is intended to assist ambulatory individuals, was eva-luated by the ambulatory group only. The inserts with recessed and side handles, which were designed for ambulatory as well as non-ambulatory individuals, were used by all participants. The standard, accessi-ble toilet, which served as a base-line for comparison, was used by all participants.

A pre-trial interview collected demographic, cognitive, and medical/physical information for each participant. The test trials consisted of asking each participant to approach and get on the toilet, stay seated for a short time, and get off the toilet. Each trial was videotaped from the side with a tripod mounted camera and from overhead by a camera mounted on the wall of the toilet room mock-up. Post trial interviews consisted of questions related to safety, ease of use, and the helpfulness of the bars or the handholds.

RESULTS

Sample: Sixty eight individuals participated in the study. Ten (14.7%) of the participants were ambulatory, 29 (42.6%) were non-ambulatory wheelchair users, and 29 (42.6%) were semi-ambulatory. The sample was almost equally divided between those under (48.6%) and those over (51.4%) 60 years old. The mean age of the sample was 58.2 years, with a range of 20 to 102 years old. The mean age of the ambulatory group was 68.3 years, the non-ambulatory group was 43.5 years, and the semi-ambulatory group was 68.9 years. There was almost a 9:1 ratio of male participants (89.7%) to female participants. Within subgroups, males accounted for 77.8% of the ambulatory group, 86.2% of the non-ambulatory group, and 96.6% of the semi-ambulatory group . This is a result of the largely male population at the VA Medical Centers and the SCI Center of the Medical College of Wisconsin which was the source of most of the participants.

Self report data. The ambulatory group rated the insert with vertical handles as the safest (50.0%) and best (57.1%), as did the semi-ambulatory group (46.7% and 50.0%, respectively). The non-ambulatory group, however rated the recessed handle insert as the safest (52.4%), but split on the rating of best between the recessed handle insert (38.1%) and the side handle insert (38.1%). All three groups rated the existing toilet with raised toilet seat as the most difficult to use (ambulatory 57.1%, non-ambulatory 81.8% and semi-ambulatory 66.7%). The non-ambulatory group, which was the only group to use the straddle toilet, rated this fixture as safer (68.4%) than the standard toilet as well as more difficult (55.0%). However, this group preferred the traditional transfer to a toilet over the straight-on transfer required by the straddle toilet (72.7%). As a consequence, 58.8% stated that they would rather purchase a traditional toilet than the straddle design.

DISCUSSION

Preliminary analysis of the data indicates that people with disabilities and older people perceive that the new fixture prototypes enable safer transfers and better accommodate bowel care than do existing toilets. In addition this study corroborates data from a previous study of grab bars use (Sanford and Megrew, forthcoming, 1994), that found that the frequency of use of rear grab bars was minimal. In fact, the significant decline in rear bar use with the insert makes the utility of rear grab bars questionable in these circumstances.

In conclusion, this research points out the critical need to evaluate existing devices with representative user groups in order to develop appropriate assistive devices, and home modifications for disabled and older people. Based on the preliminary result of the evaluation of these fixtures, recommendations for their design modifications will be made. The investigators will be working with the Technology Transfer Section of the VA Rehabilitation R&D Service to impliment these recommendations.

REFERENCES

Sanford, J.A. and Megrew, M.B. (forthcoming). Evaluation of grab bars to meet the needs of elderly people. *Assistive Technology, 7 (1).*

ACKNOWLEDGMENTS

The authors wish to acknowledge the partici-pation and support of Edmund H. Duthie, M.D., Chief of Gerontology, Sue Kartes, RN, Geriatrics Nurse Practitioner, Nursing Home Care Unit, and the Physical Therapy Department at the Clement J. Zablocki VA Medical Center, Milwaukee; of Paul Sandford, M.D., and Kathy LaFavor, R.N. Clinical Nurse Specialist at the SCI Center, Froedtert Hospital, Medical College of Wisconsin.

The project reported in this paper was funded by the VA Rehabilitation R&D Service, Dept of Veterans Affairs, Merit review project E-666-RA.

Pascal Malassigné, IDSA,
Research Service (151)
Clement J. Zablocki VA Medical Center,
5000 W. National Avenue
Milwaukee, WI 53295.1000
414.291.8069(voice)   414.291.8077 (fax)

ACCESS TO BANKING MACHINES

Betty Dion
BETTY DION ENTERPRISES LTD.

Abstract

Automated banking machines (ABMs) have changed the way Canadians do their banking over the last ten years. In fact, seventy percent of all routine bank transactions are now done with ABMs. The Americans with Disabilities Act and the Canadian human rights commissions require that persons with disabilities be accommodated, but why are banking machines still so inaccessible when the technology is already available? The session will include a brief overview of study and findings of an accessibility audit of banking machines conducted by the author. The accommodations required for an accessible machine to be discussed include such issues as audio output, large screen displays, smart card programming, appropriate height/reach locations, moveable screens, single function envelope dispensers and standard transaction codes. One result of this research has been the commitment to develop accessibility guidelines for banking machines.

Background

People with disabilities are seldom able to conduct their banking by utilizing the omnipresent banking machines. The Canadian Human Rights Act which protects people with disabilities from discrimination has jurisdiction over all federally regulated banks in Canada. The Canadian Human Rights Commission recently contracted with the author to conduct a study to measure the accessibility of automated banking machines.

Objective

The Commission's objective in conducting these studies was to initiate improvements in accessibility for persons with disabilities without relying on the human rights complaints-driven process to bring about change. The objectives of the study were to research technology for accessible banking machines, to survey a randomly selected sample of banking machines/sites and to report on the extent of compliance with the recognized CSA/CAN B651-M90 Standard on Barrier-free Design.

Method/Approach

Technologicalsystems or devices used in the design of accessible banking machines available in Japan, the United Kingdom and the United States were researched. Armed with the results of the research and comments from a Focus Group Meeting of representatives of organizations of persons with disabilities, a survey instrument was developed. A complex computer coding schedule was developed for analyzing data. Each question was weighted and rated for its important to each of eight disability groups.

Investigative staff consisting of people with a wide range of disabilities conducted the accessibility audits of the randomly selected sites. Data was analyzed and results tabulated.

Issues

For people with mobility impairments some of the key issues were the height and reach ranges, the appropriate kneespace, the design of dispensers to allow someone with limited mobility to extract envelopes or cash, and adequate time allowance between transactions to conduct business without the system being shut down or the card being ejected.

Issues of concern to people with visual impairments include various components in the design of the screen, from the contrast and glare, to the size and font of the print. For visually impaired persons who were unable to see the screen, there were varied opinions on the preferred mode of audio output but they emphasized the need to have audio feedback on all aspects of the transaction.

Elderly people who participated in the study mentioned difficulties with opening entrance doors, the complexity of the banking machine itself as well as issues such as the visibility of the screen and reasonable time allowances between transactions.

Banking Machines cont'd

People with developmental or learning disabilities mentioned issues such as glare and the legibility of the screen, the use of easy to understand language and adequate time allowance.

The development of smart card technologies is emerging as a technological solution that could be used to individualize accommodations and address many of the concerns identified.

Results

The results were very discouraging, particularly as the technology to provide accessible machines is available and in use elsewhere.

It was found that only 4% of the locations surveyed were accessible to persons who use wheelchairs and only 8% were accessible to persons with visual impairments and persons with learning disabilities who required audio output.

Improvements were found in the design of the entrances and door configurations to enable people who use wheelchairs to enter the banks, but few banking machines provided their card slots within the acceptable reach and height specified by the CSA Standard.

One of the most surprising results was the discovery that one bank provided audio support to customers with visual, learning or developmental disabilities via a telephones available beside their banking machines. People with disabilities who requested assistance via the telephone were able to obtain descriptions of information on the screen and were informed of all transactions as they were being conducted.

There was a wide variety in the time provided for customers to conduct their transactions. Some banking machines provided only 15 seconds, after which time the customer's card was ejected and they had to commence the process again. Other machines were more understanding and asked the customer if they needed more time.

Improvements were found in the design of the screen at some locations with larger type size and better contrast but problems remain with glare and inadequate illumination of the characters.

Some focus group members had identified a problem when they made two or three mistakes entering their data. It was found in some cases that the customers bank card was ceased if more than three mistakes are made, other machines refused to accept further transactions. This, of course, is a security feature to protect customers whose cards may have been stolen, but sometimes resulted in considerable inconvenience to customers with mobility impairments. In one case the customer had to go to another location of a bank to retrieve their card.

Discussion

The study served to bring to the attention of bankers and manufacturers the issue of lack of access to banking machines. This increased awareness and commitment to change has resulted in the formation of a Task Force to develop accessibility standards for automated banking machines. The task force will include representatives of the banks, banking machine manufacturers, organizations of persons with disabilities and building code officials.

This task force will examine the pros and cons of various technologies and systems to ensure that banking machines are accessible to customers with disabilities.

References

The Canadian Human Rights Act, 1988, The Canadian Human Rights Commission, Ottawa.

The CSA/CAN B651-M90 Standard on Barrier-free Design, Canadian Standards Association, Toronto.

The Americans With Disabilities Act, 1992, Washington, D.C.

Betty Dion has been a consultant in the field of barrier-free design for over ten years. She has conducted a number of accessibility studies for the Canadian Human Rights Commission including federal government offices, banks, postal outlets and banking machines. She is a member of the Canadian Standards Association Committee on Barrier-Free Design.

Betty Dion Enterprises Ltd. 458 Melbourne Ave. Ottawa, Ont. K2A IW3

STRATEGIES FOR IMPROVING ACCESS TO THE INTERNET AND WORLD WIDE WEB

Jon Gunderson, Ph.D.
Division of Rehabilitation Education Services
University of Illinois at Urbana/Champaign, USA

ABSTRACT

Full accessibility to information super highway requires looking at all of the components of the system. For people with disabilities to fully participate in the information age they need to have more than just access to information on the World Wide Web(Internet in USA) through accessible browsers and data structures. Total participation includes the additional capabilities to create and edit their own information to be placed on the Web. The ability to access, create and edit information on the Web and other future highways will be an important skill in the coming years. People with disabilities with these skills will have greater educational and employment opportunities as the use of the Web and other new electronic highways expand. This paper discusses the strategies for full participation to the Web by people with disabilities.

INTRODUCTION

Access to the World Wide Web and other electronic highways that will be built in the next decade, will be important to people with disabilities for two reasons. First, people who cannot use the electronic highways or do not have the skills in using the highways will be restricted in their opportunities in employment, recreation and education. The restrictions are similar to people who do not have good reading skills in today's society. Access to the information highways will become an important "literacy" skill in the next decade. The second reason is that people with these skills will be in demand, especially in the early development of the Web and other electronic highways. This demand presents an opportunity for people with disabilities who are traditionally under employed. If people with disabilities can get on the information super highway early, they will have marketable skills to offer a wide range of businesses planning to use the highways. But for this to happen the highways need to be accessible.

The usability of the information on the Web (Internet in USA) to people with disabilities will be dependent not only on the accessibility of the Browsers (like NCSA MOSAIC and Lynx), but also the structure of the information available on the Web and the tools used to create and display information placed on the Web. Web browsers need the capabilities to provide Web navigation controls that are usable by people with different movement capabilities and support the presentation of information in more than one form for people with sensory and cognitive disabilities. The key to supporting alternative access is the ability to have information on the Web available in more than one form and to have the information organized in a way that supports the underlying meaning and structure of the original information. One example is sound. Sound information that is available on the Web needs to also have closed captioning of the speech or a description of what non-speech sounds are trying to communicate for people with deafness and severe hearing impairments.

In addition to browsers and data structures, the tools designed to create and edit information to be placed on the Web need to be accessible. There are two reasons for the availability of accessible tools. The first is that any changes in the information infrastructure to provide accessibility to people with disabilities needs to be supported by the tools used to create the original information. Otherwise it will be too easy for the additional information to be "left out" or ignored by developers. If additional access information is not easy to add most people will not add it and while the infrastructure will be accessible there won't be a lot of accessible places for some people to go. The second reason creation tools need to be accessible is that for full participation on the Web, people with disabilities need to be more than just passive viewers of information. People with disabilities need to be able to create and modify information on the Web for business, educational and recreational purposes. Web accessibility needs to look at the accessibility of the full range of browsers, file viewers, information infrastructure and creation/editing tools.

GENERAL ACCESS CONSIDERATIONS

The task of restructuring the Web for accessibility involves all components of the Web: the data structures used for representing information (HTML, MPEG, GIF...); the tools to navigate through the Web (MOSAIC, Lynx, ...); specialized viewers used to look at images, motion pictures and to hear auditory information; and the tools to create the original forms of the information for the Web (for example Hot Metal).

Navigation with Browsers

In general to reach the broadest number of people with disabilities the tasks associated in controlling Web navigation need to have multiple selection techniques, including both the current mouse implementation and keyboard equivalents. Ideally the keyboard equivalents need both sequential and direct selection capabilities. Serial access requires only a minimal number of keys for executing commands and allows people to move to all of the items in a list of options. The serial access mode assists people with small ranges of motion and provides users with visual impairments the ability to find all of the controls in the current focus of a program. Direct access features allow faster and expert selection of a known command for people with the motor skills to use the additional keys efficiently or by experienced user with the knowledge of the command they want to execute. Direct access to commands is especially useful when moving through HTML documents with a large number of links. Most current browsers of Web information are currently designed with mouse only commands for many critical operations like selecting hot links. This is a severe restriction to people who have poor mouse skills and people with blindness who do not have good mouse access.

Navigation includes not only the control commands used to select options, but also the type of feedback to the user the command provides to identify the task the user has entered. Currently the primary output for the Web is highly visual: using text, pictures and graphic symbols, with a growing use of audio in audio wave files and motion pictures. The current capabilities of browsers like NCSA MOSAIC provide the means for information to be presented in visual and auditory modes with the use of specialized viewers, but it is currently not the choice of the user to decide which mode they receive. The format of presentation is typically fixed by the source of the information and if the user needs it in a different form there are currently no standard ways for the user to get the information translated. Therefore the same information on the Web must be structured for multiple/simultaneous presentation formats. Text information needs the capability to be viewed as either text, speech, Braille or any user selected combination. Pictures and movies need text description annotations that can be spoken or viewed visually. Auditory information must be captioned with text or have some type of visual representation to present the non-speech sounds visually to people with hearing impairments.

The vast majority of information currently on the Web though is still text formatted in a mark up language called HTML (Hyper Text Mark up Language). When exploring a document the user must also be able to understand the underlying structure of the HTML text they are viewing and receive feedback that is compatible with their perceptual capabilities. The user needs commands to move between the structured headers of HTML with inclusion of commands to move up or down the hierarchy of headers and paragraphs in a HTML document.

Modifications to Infrastructure

Current Web data structures need to be modified to include additional information for alternative presentation in formats that include audio, pictorial, text or tactile presentation. In the last section on navigation it is stated that improved navigation controls will only truly be useful if the feedback the user is receiving during navigation is appropriate for their disability. As users with disabilities explore information on the Web they must have access to the information they are exploring in a form that is compatible with their capabilities. Web documents need to have additional information built-in that describe the contents and organization of the document. For example when the image of a black bar is used to separate two text topics in a document, a user with blindness needs to understand that the image is used for spatial separation and not an image related to the content of the text itself. If the image contains new or related information to the text displayed it should have a text description available that can be accessed by the user with blindness. The access information gives the blind user the benefit of the image information and the ability to discuss the image contents with peers who can see it. Currently the only information the user receives about the image is that it is an "image". They do not know the purpose or importance of the image or have the ability to discuss the image intelligently with a colleague with out the assistance of a sighted person. Providing richer data structures therefore is a very important part of access in the design of the Web and other information highways.

Modifications to Viewers

Browsers typically call other programs to do work for them like displaying: TIFF and GIF image files, MPEG movie files, and WAVe sound files. Changes to the infrastructure will require viewers to have the capability to display information in an alternative format. When a GIF file is presented its title and description could be announced, or closed captioning of MPEG moves could automatically appear as a user selected option. Most viewers today are shareware, but as the information on the Web becomes more complex the viewers will probably be sold through more traditional commercial venues. The new commercial companies will want to support all the features of the shareware versions (plus probably a lot of other features). Therefore working with smaller shareware developers to build in features into current viewers now will be easier than trying to convince larger companies to put them in later.

Accessibility of Tools

Tools used to develop Web data structures must be modified to include the additional information required for alternative presentation formats (infrastructure changes) and to allow people with disabilities to do more than view information currently on the Web. Users with disabilities need to be able to add their own information to the Web to have the same social, educational and economic benefits of the Web.

The modification of the Web information creation tools, need to require or prompt the creator for additional information that can be placed into Web data structures to make them more accessible(i.e closed captioning information for an MPEG file). With automatic prompting or presentation of the data fields, with a requirement (or at least a prompting that requires an active cancellation for not filling in the fields) to fill them in before moving on to the next item, the features will become more difficult to not fill in. The automatic prompting will also be an educational tool by making people aware that they need to provide additional information for accessibility. In any case with auto-prompting features people could not make the excuse that they didn't know to put in the accessibility information in there information.

The Web information creation tools need to also be evaluated for accessibility in a similar manner as the browser and viewer technologies. If these tools are accessible people with disabilities will also have the capabilities of creating and editing information for the Web and other future electronic highways.

CONCLUSIONS

Full accessibility to the Web and other future electronic information highways depends on a holistic view of the system. Electronic highway browsers, viewers, data structures and creation tools all need to be designed for accessibility. In addition to the hardware and software changes, opportunities for people with disabilities to learn about and participate on the electronic highways need to be encouraged and supported. Only when people with disabilities fully participate will accessibility be achieved. The Web and future information highways can provide both barriers and opportunities. The opportunities can be expanded by building in accessibility features as soon as possible to electronic highways; and creating opportunities for people with disabilities to use the highways for education, recreation and economic purposes.

ACKNOWLEDGMENTS

I would like to thank Joseph Hardin, Director of NCSA MOSAIC research for his support of the accessibility of Web browsers; Drew Browning, Chair of the NCSA MOSAIC accessibility team at UIC; Larry Scadden of NSF for providing support to begin this research project; and the rest of the NCSA MOSAIC accessibility team for their energy and efforts on this and related projects.

INVITATION

Any one interested in participating in the usability studies of MOSAIC I urge them to contact me. As modifications are made to NCSA MOSAIC we want to test the modifications with as wide a range of users as possible to provide design feedback of new features to the NCSA MOSAIC programming team.

Jon Gunderson, Ph.D.
Chair: Mosaic Usability Testing Sub Committee
Division of Rehabilitation Education Services
University of Illinois at Urbana/Champaign
1207 S. Oak Street
Champaign, IL 61820

Voice: (217) 244-5870
Fax: (217) 333-0248

email: jongund@uiuc.edu

ADAPTIVE CANOE EQUIPMENT DEVELOPED BY PROJECT P.A.C.E.

Sherry M. Rovig, J. Martin Carlson, Mark J. Payette, John W. Theis,
Greg Lais, Nancy A. Simmet, Elizabeth A. Hearn
Tamarack Habilitation Technologies Inc., St. Paul, MN
Wilderness Inquiry, Minneapolis, MN

Abstract

This paper describes two pieces of adaptive canoe equipment developed by project PACE: the paddler's seat and combination portage frame/rowing system. PACE stands for "Providing Adaptive Canoe Equipment", and was a joint project of Tamarack Habilitation Technologies and Wilderness Inquiry.

Background

One of the most appreciated forms of outdoor recreation in Minnesota is canoeing. The goal of Project PACE is to provide people with disabilities access to waterways by developing and making available appropriate adaptive canoeing equipment. The goal was first set in motion by brainstorming sessions with consumers, wilderness recreation professionals, and designers. Problem definition, design proposals, design criteria, and existing equipment were discussed at these sessions.

Statement of the Problems

Groups and individuals have worked out a variety of ways to enable people with mobility impairments to access and enjoy canoeing, however, there were a number of areas that still needed attention and difficulties that hadn't been adequately addressed. Those included: portaging over rough terrain, transferring into and out of the canoe, effective and comfortable canoe seats, and an efficient one-armed paddle. Project PACE was developed in response to those needs.

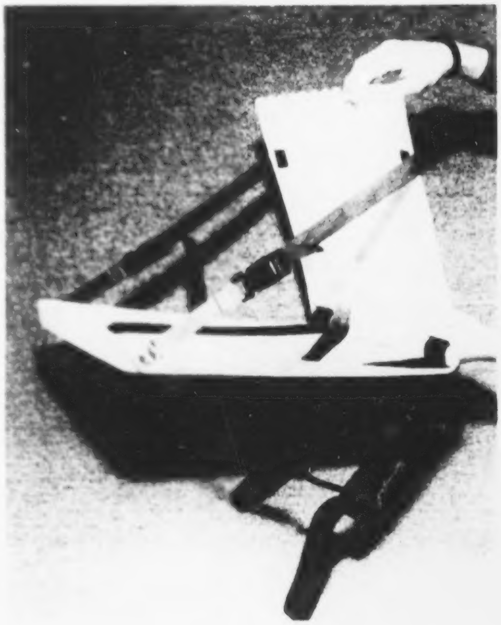
Rationale

Overall design criteria included: light weight, durable, easy to set up and use, easy transport, functional, good appearance, sensitive to the user's dignity, adjustable fit (where applicable), and good value.

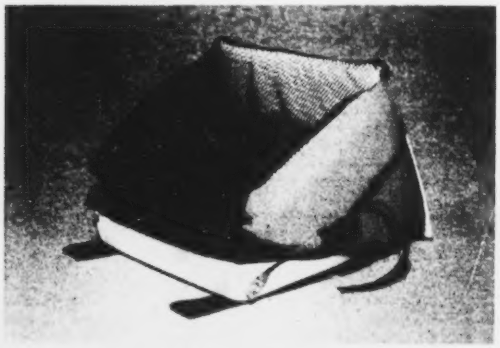
Designs

PADDLER'S SEAT: This piece of equipment was developed to provide a versatile portable sitting support for canoeing that would help stabilize the lower torso of the paddler, particularly those who don't brace with their legs or who have moderate postural instability. Cutting down on extraneous movement while paddling provides the most efficient power transfer to the craft. It also increases the comfort and stamina of the paddler. For safety reasons pelvic belts or other restraints could not be used. We wanted it to accomodate personal wheelchair cushions and to provide some adjustment for individual size, as well as doubling as a camp seat, and transporting easily. The sitting height of the paddler was kept low for better balance.

The paddler's seat is connected to the canoe via two straps with an anti-skid mat underneath. The seat pan is 1/4 inch polypropylene that has three sides flanged for strength



and to contain whatever cushion is used. It is long enough to provide some distal thigh support. The lower seat back is connected to the seat pan via dacron hinges and is constructed of 1/8 inch copoly (a type of plastic) with adjustable thickness cushioning material. The seat to back angle is determined by adjustable straps connecting the two. These straps are also a tension element providing the structural support for the seat back. Lateral support bolsters of adjustable thickness are attached to the back fabric and fit inside the straps that determine the seat to back angle. A variety of seat and back cushions were made out of closed cell foam (it floats). One version is a polyethylene wedge that can be placed underneath a wheelchair cushion to produce a pelvic recess to enhance the paddler's stability. The fabrics used were wet suit material and mesh so that the equipment would suit a nautical environment. The ability to customize the fit was especially appreciated.



PORTAGE FRAME/ROWING SYSTEM: This equipment was developed in response to several needs: portage assist, transfer assist to and from canoe, support frame for sling seat, and efficient one armed paddling (rowing).

The sling seat that fits in the portage frame was developed some time ago to accomodate individuals who could not sit safely on a canoe seat. This had previously been attached to holes drilled in the canoe's gunwhales and while not effectively positioned for paddling, it provided needed sitting support. We added adjustable thickness lateral bolsters to the sling seat design to provide even more extensive support. The portage frame provides a support system for the sling seat that doesn't require modifying the canoe. It is a free-standing frame that allows the person to be transferred to the sling seat on land and the occupied frame is then placed in the canoe.

After extensive discussion and review of one armed paddling options, it was concluded that a mechanical advantage was needed to efficiently propel the boat. The existing one-armed paddles all require such high expenditures of energy that they can only be used for short periods of time by most people. The advantage of rowing with the oarlock and pin providing the fixed pivot point was obvious and also works well for people with bilateral, but impaired, upper extremity function.

Extensions were made to attach to the portage frame that provide efficiently positioned oarlocks. Clamp-on oar pins can be attached to canoe paddles. The rowing extensions for the portage frame can be attached to either or both sides of the unit for one or two paddles. The freestanding frame with the sling seat attached also made an excellent camp chair.

The original prototypes were made of stainless steel tubing for convenience of fabrication. Testing is currently being done on an aluminum version and various methods of portaging including poles, straps, and wheels.

Development

Each piece of equipment went through prototype development and testing, subsequent revisions and retesting, and are currently being tested on longer trips. Special canoe events in Minnesota exposed a significant population of people to the devices and their evaluations were obtained through one on one interviews and questionaires.

Evaluation

The equipment developed is already in use and demand. The potential is good for further refinements after more extensive use, but the effectiveness of the basic designs has been established. The paddler's seat would probably accomodate even more people if there were at least two different sizes of back and seat pan.

The portage frame/rowing system was very well received. The aluminum version will have the advantage of lighter weight.

Discussion

Many people with disabilities already know the pleasure, excitement, and restorative powers of canoeing, though they are often limited to the role of appreciative passenger. The opportunity to be a contributor to the motive power of the canoe in a dignified and efficient way has been less available to many. These pieces of adaptive canoe equipment make significant progress to this end, as well as increasing the safety and comfort of participants.

References

Payette, Mark J., and Mary Kay Albanese. "Access to Outdoor Recreation: Two Adapted Gear Designs." Proceedings, Resna 8th Annual Conference 1985.

Acknowledgements

Project P.A.C.E. was funded by a grant from the MN STAR Program (a System of Technology to Achieve Results). We thank them for the opportunity to work on such a satisfying project. Some of the individuals who made significant contributions to the project are: Maggie Wille, John Galland, Carl Anderson, Dianne Goodwin, Ann DeLavergne, The Newburg family from Spring Creek Outfitters in Mt. Iron, MN, and Wilderness Inquiry and Tamarack staff.

Sherry Rovig
Rehabilitation Technologist
Tamarack Habilitation Technologies, Inc.
1471 Energy Park Dr.
St. Paul, MN 55108
(612) 644-9950

DISABLED ADVENTURES - DEVELOPING AND PROMOTING ACCESS TO OUTDOOR RECREATION IN SOUTH AFRICA

Carol L Schafer
Department of Sports Science, UCT Medical School
Observatory, Cape Town, South Africa

ABSTRACT

In many first world countries there is a great awareness of the outdoor recreation abilities and access needs of people with disabilities (PwD). This is reflected by the provision of many recreation facilities and programmes. In South Africa, with its blend of first and third world conditions, outdoor recreation for PwD has received little attention.

Since 1991, DISABLED ADVENTURES, an outdoor recreation club for PwD, with an emphasis towards those with a spinal cord injury (SCI), has worked to develop and promote access and increase awareness of the need for and benefits of outdoor recreation for PwD.

BACKGROUND

In South Africa, in comparison to many countries overseas, the awareness of the need for access for people with disabilities (PwD) and the provision of this access has been poor. In 1985 Part S of the National Building Regulations were issued with specifications for the provision of access to public buildings(1) Even so, many buildings constructed since these specifications were issued are not accessible to PwD. In 1992 the National Environmental Accessibility Programme (NEAP) was initiated. The aim of NEAP is to promote, advocate and lobby for access for PwD. Areas of focus include legislation standards, transport, tourism, rural areas and communication. In spite of these recent developments, access to outdoor and wilderness areas and for outdoor recreation is still a neglected area.

In contrast to the South African Sports Association for the Physically Disabled, which developed and organises sport at provincial and national levels, prior to 1991 there were no organisations or clubs promoting or developing outdoor recreation for PwD in South Africa. Magazines such as Sports 'n Spokes showed the numerous outdoor recreation and adventure activities that overseas counterparts were involved in and what was still possible for PwD.

PROBLEMS AND OBJECTIVES

The spinal cord injured population in South Africa differs from that of overseas countries. For example, injury statistics from Conradie Hospital Spinal Unit, Cape Town, which services predominantly the Cape Province and Transkei areas, record an equally high percentage of injuries as a result of violence related accidents such as gunshot (10%) and stabs (30%), mostly a result of township violence, to that of motor vehicle accidents (40%). Falls (10-15%) and a small percentage of sports injuries, mainly rugby and diving, bring the total to approximately 310 injuries per annum.(4) At the present time, for most of the people with violence related injuries, access to their home environment and coping with basic mobility and health issues are of primary importance. To them, access to outdoor recreation is, as yet, a lower priority. DISABLED ADVENTURES would like to enable this group of people to gain access to outdoor recreation and enjoy its benefits.

For those people who are interested in continuing their recreational pursuits, once they leave the Spinal Unit, it is their own responsibility to investigate modifying the activities they were involved in or to find alternative recreation activities. There has been no recreation centre or organisation to assist them. There is a lack of awareness among many of these people as to what activities are still possible and what resources are available. In addition, managers of facilities are generally unaware of the need for access or how to provide it.

There is a need to develop a resource centre or organisation to provide for these recreation needs which include:

- to increase the awareness of PwD and the general public
- to educate managers of facilities or companies of the possibilities in outdoor recreation and how to provide it
- to provide a database of information relating to outdoor recreation
- to develop adaptive equipment
- to organise and provide activities

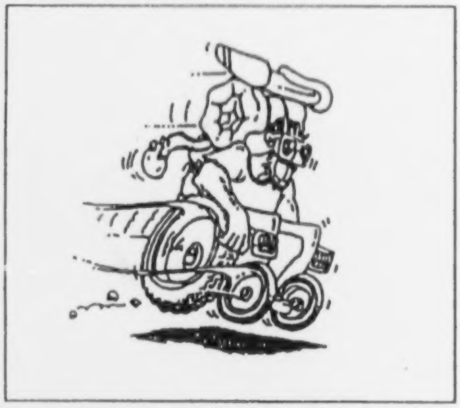
DISABLED ADVENTURES

DISABLED ADVENTURES is based in Cape Town and due to financial restraints its activities are limited to those PwD in that area. A national organisation is needed that can provide activities in other provinces as well.

APPROACH:

In 1991 a group of individuals organised the Outeniqua Wheelchair Challenge - a three day hike over 36 km on forestry roads in the Outeniqua Mountains, in Knysna, Cape. Nine adults (eight adult paraplegics and one adult bilateral above-knee amputee) and one young boy with cerebral palsy were assisted by 20 able-bodied helpers. This was the first hike for PwD in South Africa. The hikers in wheelchairs had to use their day chairs and cope with some inaccessible overnight hut facilities. In spite of this, the success of the hike initiated the formation, in April 1991, of DISABLED ADVENTURES, the first outdoor recreation club for PWD in South Africa .

DISABLED ADVENTURES
OUTDOOR RECREATION
CLUB



OUTDOORS FOR ALL!

During the past four years the club has operated on a voluntary basis and does not receive funding from other organisations. Income is derived from a small annual membership fee to cover the administration costs of organising trips and sending out a regular newsletter.

Trip expenses are shared by those who participate in them. The club has no buildings or facilities, vehicles, outdoor wheelchairs or other equipment and therefore the transport and equipment for trips is also provided by participants. Day chairs, some with minor modifications are still the only chairs available for hiking.

DISABLED ADVENTURES and its activities have received some media exposure through television coverage of the Outeniqua Wheelchair Challenge, radio interviews, newspaper and magazine articles. This has helped to increase the awareness of the public. The regular newsletter is sent to members, many non-paying interested people, and other contacts. Both PwD and able-bodied people have joined and the range of disabilities represented has increased.

The club is a pioneering venture in a country where most people are not very aware of PwD and their abilities and needs. The general approach is that of promoting awareness by word of mouth among PwD and facility managers; developing activities; actively seeking new possibilities and doing "recces" to new places and facilities; investigating adapted equipment options and to grow slowly within the existing informal infrastructure until funding enables otherwise. In all its activities the club aims to maintain an "inviting", positive and active image.

RESULTS

The past four years have shown progress!

To date activities have included day and overnight hikes, weekend trips to nature reserves, bird watching, an ecology course in the Kruger National Park, Gauteng, a scuba diving course and subsequent diving weekends, canoeing, abseiling, archery and orienteering at an adventure centre, horse riding, and some individual members are involved in activities such as micro lighting and standard K2 canoe marathons.

During the past two years in the Cape some integrated facilities have been developed: the Palmiet Trail for the visually impaired is a 6km trail (most of which is suitable for wheelchair hikers as well), which forms the initial section of a standard hiking trail, an accessible bird hide at the West Coast National Park and a wheelchair accessible path in Zandvlei bird sanctuary, Muizenberg. Managers of some nature reserves have initiated modifications to make their facilities accessible e.g. Rondevlei Bird Sanctuary, Cape and Anysberg Nature Reserve, Lainsburg.

Other facilities, predominantly for the visually impaired, have been developed in the Gauteng region. In late 1994 Robert Filmer, a nature conservation officer who is a diabetic and has lost his sight, received funds to begin ECO-ACCESS which is based in Johannesburg, Gauteng. The aims of ECO-ACCESS are to develop a register of accessible outdoor and environmental facilities and to create aware ness and help to develop accessible environmental facilities. DISABLED ADVENTURES and ECO-ACCESS will work together to reach their common aims.

DISCUSSION

The positive benefits from involvement in outdoor recreation should be made available to more PwD. The past four years experience has shown that these include:

- increasing physical activity levels
- building confidence in being able to cope with the challenges of hiking in unfamiliar outdoor environments and coping with inaccessible overnight accommodation
- improving wheelchair handling and mobility skills on the rough roads and downhill stretches
- interacting with and gaining help from "more experienced peers" who act as role models;
- integrating PWD and able-bodied people
- increasing the awareness of the public and facility managers
- and spending time in nature areas and the therapeutic benefits that it has.

The major limitation is the lack of funding. Funding will not only allow the development of a resource centre but also enable the sponsorship of people who cannot afford to participate in outdoor recreation .

At present when approaching managers regarding improving access, one of the issues they raise is that of the cost involved in making adaptions versus the size of the target market. At the present time the active group of SCI people and those with other disabilities is relatively small. As awareness amongst PwD increases it is hoped that more of this group will become active outdoors . One of the benefits of a larger active group will be a greater market for outdoor wheelchairs. A resulting benefit of this could be the design of a basic wheelchair suitable for those who in live in rural areas.

South Africa lends itself to outdoor pursuits. DISABLED ADVENTURES would like to see more integrated facilities where PwD can interact with able-bodied people and not necessarily "special" facilities which separates the groups.

After the Outeniqua Wheelchair Challenge, a report was prepared from answers to questionnaires given to wheelchair hikers and the supporters before and after the hike. It was suggested that fitness criteria be developed for a 3-4 day hike as this would provide valuable guidelines for participants and that the routes be graded in terms of level of difficulty .

At present the author, who co-ordinates DISABLED ADVENTURES, is involved in a Ph.D. investigating the exercise capacity of SCI people. The results will be applied to developing design guidelines for trails. This research will provide some of the answers to questions that have arisen from the clubs hiking and outdoor activities.

REFERENCES

2) Dr Newton, Head of Spinal Unit, Conradie Hospital, Cape - personal communication.

1) Part S of the Building Regulations," Facilities for Disabled Persons. SABS 0400-1990

ACKNOWLEDGEMENTS

Funding for the Ph.D. has been obtained from the Medical Research Council; the FRD Special Programme on South African Rivers and a donation from Mrs Noakes.

Carol Schafer
Department of Sport Science
UCT Medical School
Observatory 7925
Cape Town, South Africa

T: (021) 406 6242
Fx: (021) 477669
E-mail: SCHCAR06@physio.uct.ac.za

SIG-20
Cognitive Disabilities & Technology

ADULTS WITH SEVERE/PROFOUND DISABILITIES--ISSUES AND TRENDS IN TECHNOLOGY USE IN DAY PROGRAMS AND RESIDENTIAL FACILITIES

Dianne M. Goodwin and Laura M. Piché
AbleNet, Inc.

Abstract

Adults with severe/profound disabilities are underserved with regards to technology utilization. A cross-functional team has been given the task of examining ways to better meet the needs of adults with severe disabilities and adult service providers. We are examining existing barriers to the use of technology by adults, identifying staff issues and needs, learning more about adult systems and programs, identifying approaches or elements of programs that "work", identifying training needs, developing and testing new training materials, and exploring potential new product ideas.

Background

Adults with severe/profound disabilities could benefit greatly from the utilization of assistive technology. Much of the same technology used by children in the schools (switches, environmental control units, and communication devices, etc.) could be used by adults. It seems that when individuals with severe disabilities move out of the educational system with its supports and mandates, and into the realm of adult services, technology is not consistently utilized. Also, much of the assistive technology developed for adults addresses the needs of individuals who are seeking competitive employment and living independently, rather than individuals with severe/profound disabilities. Aside from the innovative, one-of-a-kind rehabilitation engineering projects at RESNA's Show-and-Tell and paper sessions and a handful of publications about jigs developed for individuals in sheltered workshops, little is written which addresses technological applications specifically for this population.

Problem

In the varied spectrum of adult systems and programs, there are rarely systems, staff or resources in place to ensure that individuals are provided with the tools and training they need to most effectively, and fully, participate in program activities. Numerous barriers exist, including attitudes, funding concerns, a lack of trained personnel, and the question of whose responsibility it is to recommend and implement the use of assistive technology. These barriers further exacerbate a situation in which limited assistive technology has been developed, and is commercially-available, for adults with severe/profound disabilities.

Objective

In an effort to expand opportunities for adults, we are exploring the needs of adults and their service providers. We are examining the barriers and issues which exist that make the use of technology difficult. In addition, we are attempting to identify and develop new products, appropriate for adults with severe/profound disabilities, which will help them more fully participate in home, work and community activities.

Program objectives are to:

-visit programs/facilities where adults live or spend their day
-observe patterns of use and non-use of assistive technology
-identify existing and perceived barriers to the use of technology
-identify existing barriers to the implemention of programs that utilize technology
-identify personnel training needs and opportunities
-identify and develop training and support strategies that facilitate the use of technology
-develop new products based on identified needs

Method/Approach

Initial information-gathering
A cross-functional team consisting of a marketing/education specialist and a product design/rehab engineer is gathering information from adult service providers in an attempt to better understand the needs, issues, trends and opportunities relating to assistive technology use among adults with severe/profound disabilities. Day habilitation, work activity, and residential programs will be included in our study. A minimum of ten sites will be chosen for ongoing observation. Site visits include meetings and discussions with various levels of staff, as well as

627

ongoing observation of program participants. Baseline information is gathered at each site with respect to observed technology use in their programs, attitudes towards the use of technology, awareness, and responsibility for technology assessment and implementation.

Intervention strategies
Different strategies to increase the creative and functional use of technology will be developed and implemented. These may include some or all of the following: training, technical assistance, brainstorming, introducing new application ideas, empowering the staff and consumers to identify and implement new ideas for technology use, identification of product needs, and field testing potential new products.

Evaluation of efficacy of strategy
Outcomes such as increased activitiy options, improved productivity, and increased independence will be monitored and used in assessing the effectiveness of the different interventions.

Results

We will present information gathered as the result of our field observations. By June, we will have developed and tested various training and intervention strategies, identified and tested a number of potential products for resale, and gathered information regarding new product needs and ideas.

Discussion

The initial investigation has been met with much enthusiasm and we have seen a variety of approaches and issues. Service providers want to be able to offer adults with severe disabilities with more options. They are very willing to participate; we have heard, many times, "Finally, someone is addressing the needs of adults with severe disabilities." The people we have spoken with feel there is a very real need for new staff training and implementation strategies, new products, and new ideas as to how to approach providing technology for this underserved group.

For further information, contact:

Dianne M. Goodwin
Laura M. Piché
AbleNet, Inc.
1081 10th Ave. S.E.
Minneapolis, MN 55414-1312
USA

1(800)322-0956
1(612)379-0956

ARCHITECTURAL BARRIERS TO NORMALIZATION: THE ACOUSTIC ENVIRONMENTS OF GROUP HOMES

Scott M. Shea, M Arch. Research Associate, Kelly Chur, Research Assistant,
Maureen E. McBride, Research Assistant
Center for Assistive Technology/ Adaptive Environments Lab, State University of New York at Buffalo

Abstract

Normalization of group homes entails more than the visual appearance. Non visual features such as poor acoustics can be just as important. There may be a relationship between poor acoustics and resident comfort and behavioral outbursts. Several group homes in Western New York were studied to determine the extent of poor acoustic conditions and their causes. Size and material choices, in conjunction with the use of space contributed to poor acoustic conditions. Recommendations are made to address acoustic problems, as well as suggestions for future study.

Background

Normalization, or the integration of the individual into the prevalent culture of society is the operant philosophy behind deinstitutionalization of people with developmental disabilities. It is the rationale behind the construction of community residences and group homes. The need to provide for health and safety for the residents as well as budgetary constraints, however, often conflict with the goal of normalization. Visible fire safety equipment and "institutional" surfaces and furniture designed to be easy to clean are examples of this conflict.

Resolving such conflicts is a major goal of research concerning group homes. There are many examples of studies that seek to provide guidelines for creating more homelike environments in group homes (see for example Robinson et.al., 1984). These studies are primarily concerned with the visual environment. However there is more to environmental experience than how a place looks. J.J. Gibson characterized human experience and perception as the interaction of five systems: visual, auditory, taste/smell, haptic and orientation (Gibson, 1966. pg. 4) Traditional conceptions of perception acknowledge the five senses: taste, touch, smell, vision, and hearing. Thus perceptual theory suggests that there are additional aspects to normalization beyond appearance.

In particular, acoustics can have a strong impact on the character of a place. What acoustic issues in group homes affect normalization, health and well being of the residents? There are a range of concerns, from the physical comfort of the residents, the safety and stability of the staff's working conditions, as well as questions about the relationship, if any, between acoustic problems and behavioral incidents among residents with autism and other disabilities.

Objective

In response to these concerns, a study was conducted to examine several group homes whose design was based on prototypical plans used throughout the state. The objective was to determine the nature and extent of any acoustic problems and recommend countermeasures that could be implemented statewide. In one case, specific design recommendations were requested.

Approach

Four homes were examined, two were based on the prototype plan. Two objective measures were used to describe acoustic conditions, reverberation time and sound pressure level. Sound pressure level is a measure of the intensity or loudness of a sound. It is measure in units called decibels (dB). Sound pressure levels are often weighted to account for variations in intensity at different frequencies, with the A weighted scale being the most commonly used. Sound pressure levels in this study were taken with a sound pressure level meter and measured in decibels using an A weighted scale, or dB(A). Decibel level rises on a logarithmic scale, thus a 50dB sound level is ten times an intense as a 40dB sound level. Sound pressure level data was obtained in only one of the four homes, as it was the only one where the residents were present. Reverberation time is a measure of how long a sound persists in a space. Rooms with high reverberation times are referred to as "live" and typically possess echoes and other distortion effects. A high reverberation time may result in reinforcement of existing sound pressure levels, createing a perceived increase in the loudness of a sound. Reverberation time is directly related to volume and material characteristics of a space.

Staff were interviewed to determine if any acoustic problems were noticeable, and if so what the nature of these problems were. Number of residents and daily routines were noted in order to determine their effect on acoustic conditions. The objective measures of the acoustic conditions were analyzed and measured compared to standard norms for residential spaces. Causes of poor acoustic conditions were determined. Recommendations were then made to ameliorate acoustic problems.

Results and Discussion

High reverberation times and sound pressure levels were observed in almost all common spaces within the homes examined, especially in dining and kitchen areas, and to a lesser extent, living rooms.

Sound pressure levels in the dining room ranged from 70dB(A) to 85dB(A), with peak noise levels as loud as 100 dB(A). Typical residential sound levels in a noisy home are in the 50 to 60 db range. Levels in the 80-85dB range are more consistent with factories and shop floors. One hundred decibels is as loud as a subway or power lawn mower (Stein et. al. 1986, pg. 1242).

Figure 1 shows the reverberation times for each band of the audible frequency spectrum, as well as the average reverberation time across them. The average reverberation times for various spaces in the homes examined concentrated between .73-.79 seconds. In the kitchen and dining areas, higher frequencies have reverberation times between .93 and .96 seconds. This is particularly relevant, as higher frequency sounds are more disturbing. Recommended reverberation times for clear and intelligible speech for these room types and sizes are in the .4-.5 second range.

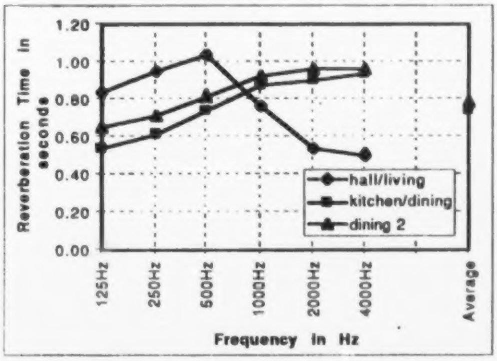


Figure 1. Reverberation Times by Room

Staff reported the presence of echoes in certain rooms, the ability to hear noise from one room throughout the homes, as well as generally loud noise levels during certain periods of the day.

The causes of acoustic problems stemmed from two sources, "signal" and the design of the homes. Signal refers to the noise generated. The homes have from 8 to 12 residents, plus four or more staff members present at any given time. Activities that concentrate all of these people in the same place such as eating or recreation are accompanied by other noise sources such as rattling of dishes and pots, use of appliances, television or radio noise and vocalizations and physical noises generated by the residents and staff. The combination of these factors generates much more noise than in a typical home. The amount of people alone could accommodate for elevated noise levels. During instances of shouting, screaming, or other behavioral outbursts, noise levels can rise high above the norm.

The design of the physical environment contributes to the poor acoustic conditions in several ways. Reverberation times are directly related to the tendency of a building material to absorb sound. Generally, soft and porous materials absorb more sound than hard and smooth materials. Painted drywall, tile floors and other hard materials are often used in group homes because of their low cost, ease of maintenance, durability, and compliance with fire codes. Materials that would improve the acoustic conditions such as carpeting, curtains and residential "acoustic" ceilings are not usually used because they would result in higher first costs and life cycle costs, as well as concerns over durability and maintenance. Some of these materials cannot meet the fire codes mandated for group homes. Without materials with good acoustic performance to offset the poor materials, the problems of high reverberation times, echoes and other distortions will persist. High reverberation times also tend to make the perceived noise level higher, potentially aggravating an already poor situation. Features that are intended to contribute to the visual homelike quality of group homes may also adversely affect the acoustic conditions. In one home, light wells in the ceiling of the dining room contributed to a higher reverberation time as well as distortion effects of sound in the room.

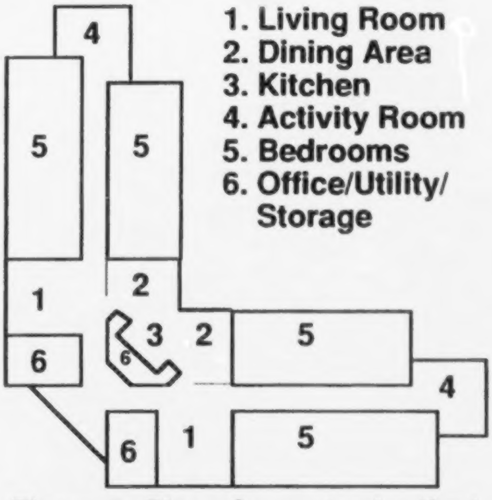


Figure 2. Plan of one standardized group home

The physical layout of the group home can also have a negative effect on acoustic conditions. Figure 2 shows the plan of one of the prototype group homes that was studied. This particular plan has been used in over 40 homes in the Western New York area. High noise areas such as the living, kitchen and dining areas are all concentrated together. The bedroom hallways have nothing to isolate them from the living area, thus noise is transmitted throughout the home. The concentration of the activity areas tends to raise the perceived level of noise in other parts of the home.

These factors combine to create a poor acoustic environment, radically different from a typical or "normal" residential environment. At best, these acoustic conditions cause discomfort to both the residents and staff. According to some definitions of normalization, comfort of the residents is a key factor in distinguishing group homes from institutions (Wolfensberger, 1977). As the acoustic conditions get worse, increased stress can result (Rubin and Elder, 1980). Group homes, in addition to being residences, are also workplaces. Consideration must also be given to the working conditions of the staff. Increased stress levels among the staff can have an indirect, although unintentional impact on residents' well being and quality of care. Not every group home will possess these problems, but these findings do raise concerns.

Conclusions

Our findings indicate that there are several problems in the way some group homes are currently designed and managed. Group home size, materials with poor acoustic qualities, proximity of "high" noise areas, and the way these spaces are used all contribute to poor acoustic conditions in group homes. Dealing with these conditions means addressing some or all of these problems, preferably in the design and planning stages. Group home size should be smaller, to become more like "normal" residences. High quality materials that both meet fire codes and provide good acoustics should be purchased. Residential acoustic ceilings are often attractive and useful ways to deal with this issue. High noise areas, such as kitchen/dining rooms and living rooms should be separated in homes that have larger populations, and measures taken to acoustically insulate them from one another. High noise areas can also be split into separate, smaller spaces to accommodate smaller user groups, reducing noise levels.

Existing homes could also benefit from these suggestions. These homes can be retrofitted with residential acoustic materials, particularly ceilings. Curtains and draperies may also be appropriate in some homes. As of this writing the staff from the home where specific design recommendations were made to add an acoustic ceiling in the dining area report a noticeable difference in the acoustic conditions. It remains to be seen whether this change in acoustics has any effect on the number and nature of behavioral incidents. There is however, no acoustic cure all. Poor acoustic conditions must be evaluated and addressed on an individual basis to determine the best approach.

Policy and management changes can also be made. Daily routine can change to split up larger groups. One of the homes studied had two dining "shifts" in order to reduce noise in the dining area. Residents that are prone to disturbances can be placed with those that are less prone to this, both to experience a standard of normalcy, and to reduce "domino" effects. Location of activities that cause noise can also be evaluated and changed based on the existing acoustic conditions. Quiet areas can be designed for residents who are disturbed by louder noise, and wish to have some relief from it.

Additional research needs to be completed on this. Studies that examine the relationship between the presence of particular frequencies or noise levels and behavioral incidents would establish a better understanding of the effects of poor acoustics in group homes. These studies need to be carefully designed in order to control for other factors that affect resident behavioral outbursts. Research and development of more durable and easily maintained acoustic materials would provide additional options for retrofitting existing homes. Educational materials and programs for staff, administration and design professionals can also raise awareness about the issues involved, and establish a foundation for more normalized acoustic environments.

References

Gibson, James J. *The Senses Considered As Perceptual Systems*. Houghton Mifflin Company: Boston, MA. 1966

Robinson, Julia et. al.. *Toward And Architectural Definition Of Normalization*. Center for Urban and Regional Affairs, University of Minnesota. 1984

Rubin A and Elder J. *Building for People*. Washington DC: National Bureau of Standards. 1980

Stein B, Reynolds JS, McGuinness WJ, *Mechanical and Electrical Systems Equipment for Buildings*. New York: John Wiley &Sons. 1986

Wolfensberger W. "The normalization Principle, and Some Major Implications to Architectural Environmental Design." in Bedner M. *Barrier Free Environments*. Stroudsburg, PA: Dowden, Hutchinson & Ross, Inc. 1977. pg. 135

This study was conducted by the Applied Studies group at the Center for Assistive Technology at the State University of New York at Buffalo, which is funded through a grant by the Office of Mental Retardation and Developmental Disabilities.

Scott M Shea
Center for Assistive Technology/
Adaptive Environment Laboratory
515 Kimball Tower
3435 Main Street
Buffalo, New York 14214-3097
716-829-3483 ext. 330
shea@arch.buffalo.edu

THE QUARTER HOUR WATCH, A TIME VISUALISATION AID FOR PERSONS WITH DEVELOPMENTAL DISABILITIES

Lars-Åke Berglund, Anders Bond
The Handitek Foundation
Borlänge, Sweden

Abstract

Work carried out at the Handitek Foundation aims at reducing the difficulties persons with developmental disabilities encounter in their daily lives and by doing so increasing their potential ability to be more self-sufficient. An important component of this work is the development of compensatory technical aids. Aids compensating different aspects of a developmental disability help the user to be able to live a more independent life while simultaneously increasing general public awareness and understanding for the disability. This paper describes one of the products, the Quarter Hour Watch (QHW), an aid giving persons who cannot manage to use ordinary watches the opportunity to orient themselves in the dimension of time.The theoretical and empirical base for the design and the introduction of the aid are described, giving implications that can be generalised to the development of different kinds of technical aids for persons with developmental disabilities.

Background

Persons with developmental disabilities are in fact one of the largest handicap groups. Dependent on the definition of developmental disabilities, the group comprises between 0,5 and 3 % of the population in the industrialised countries.

Persons with developmental disabilities are confronted with various difficulties in their lives due to a functional impairment in their intellectual capability. Unfortunately, these difficulties are often greater and occur much more frequently than necessary, basically because our modern society is still very inadequately aware of what developmental disability really implies and how it is manifested in different concrete situations.

Developmentally disabled persons are usually to a large extent dependant on others to manage their lives. A significant factor that in many cases reduces the degree of independence is problems connected with orientation in the dimension of time. A great number of persons with reduced cognitive functions lack the ability to use an ordinary clock or watch.

Quite a number of attempts have been made to solve this problem. Various clocks and watches have been made; clocks with only one hand, clocks with pictures, clocks with voice output etc. All these ideas share a common focus on making it easier to read the clock dial. Usually these solutions contribute minimally towards increasing the ability of the person with a developmental disability to deal with time.

Rationale

Time is an abstraction based on the perception of sequence and duration of events. We measure time with clocks and watches that indicate the momentary value in a theoretically defined time variable. Using a watch in a practical situation, e.g. to estimate the time remaining until a certain event, presupposes a series of abstract processes. You must know the time value of the anticipated event and subtract that value from the value shown by the watch. Furthermore, to make this result of the mathematical operation meaningful it must be related to previous experience of events or activities that could be contained within this framework.

This analysis clearly shows why many persons with limited cognitive abilities do not find an ordinary watch useful and need a time aid that makes it possible to handle the dimension of time in a more concrete and direct way.

The Quarter Hour Watch was developed in order to meet that demand.

The approach adopted was to design a watch that does not show the actual time, but gives a visual representation of the amount of time remaining until an event that the user chooses. This reduces the demand for abstract operations in a significant way and in a sense makes the dimension of time visible. It gives the user the opportunity to handle quantities of time in analogy with physical quantities.

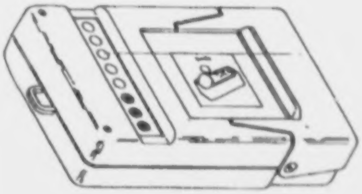
The Quarter Hour Watch

In the area of making estimates of quantities, persons with developmental disabilities generally have pronounced problems in situations demanding response to changes in a dimension that has a continuous variation. For that reason the watch was given a time scale with discrete steps, each step representing a quarter of an hour. The choice of the 15-minute period as a unit gives a scale with relatively few steps but still makes it possible to associate the duration of many common daily events with different values in the scale.

It is fully the responsibility of the user to activate the watch by choosing the event to relate to. Our experience is that people with developmental disabilities seldom have pronounced problems keeping track of the sequence of events in their life. The duration of events is the main problem.

To make a technical aid fit for use and attractive it is important that it is simple and offers the user the support he desires without unnecessary functions. It is important that user experiences that the technical aid supports independence on his or her own terms, that it does not restrict freedom by having unnecessary elements of control or automation.

Design

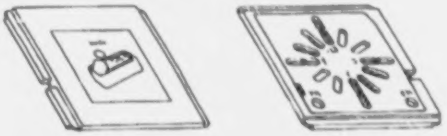


The QHW is a small (130x80x30 mm), robust device. It is easy to take along in one's pocket or in a small case.

The basic idea is that events are represented by simple, readily understandable illustrations on picture cards which are coded for a specific point in time. The coded picture card is placed on the QHW and the time remaining until the event depicted on the card is shown by luminous indicators each of which represents a quarter of an hour.

The display always shows eight circles (with a picture card inserted into the watch). The number of quarters of an hour remaining to the coded point in time is illustrated by the number of filled circles. When two hours or more remain all eight circles are filled (the point in time are considered far distant). When one hour and three quarters of an hour remain seven circles are filled etc. When the coded point in time occurs the QHW beeps and the circles flash.

The coding of the picture card is very easy. The desired point in time is marked on a disposable plastic watch face by removing the actual time segments. The disposable watch-face is then put into the backside of the picture card.



Evaluation

The development of the QHW comprised a comprehensive evaluation. Prototypes were used by fourteen users in different sites all over Scandinavia for a year. The result was encouraging, all developmentally disabled users soon used the QHW as an indispensable part of their normal living. The level of use of the QHW was different for the users, one did just use one picture card ("time to go to work"), an other user gradually increased the number of picture cards up to thirty.

Based on the successful evaluation series production was started in late 1992, and during 1993 and 1994 more than 500 QHW have been sold to users primarily in the Nordic countries. This means that we now are beginning to get extensive experience of a special designed compensatory technical aid for persons with developmental disabilities. The conclusion from the evaluation still stands. The QHW seems to function very well for most persons with developmental disabilities (moderately to mildly), giving the users a substantial increase in independence and self esteem.

Discussion

The introduction of a new technical aid to an individual with developmental disability often generates special problems associated with difficulties to understand instructions and the motivation to use the aid. According to our experience these problems can be minimised if technical aids for this group are designed to give the user an optimal chance to explore the product and gradually master the aid in his own pace. Persons with developmental disabilities are often confronted with various problems in their daily life and consequently they have experience as problem-solvers. A well designed technical aid can take advantage of this.

At the introduction of QHW to a user the instructions are kept to a minimum, they are mainly focused on putting in and removing the coded picture card. Still almost everyone of the users gradually begin to utilise the information on the duration of time that the indicators on the watch provides.

Our prediction that the managing of the sequence of events should not give any significant problems has been verified both during the evaluation and the practical use. Many users utilise cards for a considerable number of events with success. Probably this demand on personal responsibility is one of the factors that has contributed to the widespread acceptance of the Quarter Hour Watch.

Technical aids for the developmentally disabled incorporate the essential characteristic that they contribute both to an enhanced quality of life for the user while providing the prerequisites for a more efficient use of socio-economic resources.

Acknowledgements

The development of the Quarter Hour Watch was funded by the Swedish Handicap Institute, the Teknikdalen foundation and the Nordic Development Centre for Rehabilitation Technology.

Lars-Åke Berglund
Handitek
Box 773
781 27 Borlänge
SWEDEN
Tel: +46 243 736 34
Fax: +46 243 734 02

NOUN CUING FOR BROCA'S APHASICS

Blair A. Rowley, Ph.D. & Nong Ye, Ph.D.*
Department of Biomedical
& Human Factors Engineering
Wright State University
Dayton, Ohio 45435

David L. Van Winkle, Ph.D. & Janet Irwin M.S.
Audiology and Speech Pathology Service
VA Medical Center
Dayton, OH 45428

ABSTRACT

This paper describes an experiment designed to determine the cognitive problem which effects speech output when individuals with Broca's aphasia attempt to produce nouns. Cuing using text and pictures is evaluated. The results indicate that text is the better cue. This leads to the conclusion that the problem involves an inability in finding the correct verbal phrase in memory not the result of a defect in semantic concept or meaning.

BACKGROUND

Aphasia is an acquired dysfunction of the brain involving language which results in the inability of an individual to efficiently complete language input and/or output. It is estimated that there are 1,150,000 living aphasic persons in the United States. Each year a half million individuals suffer stroke and approximately 120,000 acquire aphasia (Rosenek 1989). Individuals with Broca's present with one of the most common forms of aphasia. Broca's is an acquired impairment in language production caused by damage to the brain. Such damage is usually the result of stroke and becomes more common as persons age.

Individuals with Broca's aphasia can determine, in interaction with others, which concept they want to transmit in response to a perceived input. Their difficulty lies in initiating a verbal response. As a result they are not able to retrieve words and the associated language structure from their brain in sufficient time and with sufficient accuracy to have meaningful conversations with others in everyday living. These individuals are able to generate meaningful conversation when they receive verbal and nonverbal cues provided by speech therapists using a variety of stimulus items.

The concept of using a small portable device, a Cognitive Associate (CA), to provide language cuing with which a user can continuously independently access is technically feasible today and attractive for individuals with Broca's aphasia. Such a device could be hand held, strapped to the wrist, or used with a projection system built into a pair of glasses. It could be designed to have categories of cuing for different situations, i.e., discussing the weather, ordering a meal, or current events. The idea for a cognitive prosthesis along the line of a CA was first delineated in a paper about a hypothetical Companion Aid (Vanderheiden 1992).

Numerous successful uses of technology in providing cues for learning and activities of daily living have been reported (Kirsch 1992, Cole 1992 & 1993, Friedman 1993). However, the literature does not appear to provide definitive information about what type of cuing works best with Broca's aphasia. Therefore, this study was undertaken to help provide some cuing criteria for developing a CA.

METHOD

The question: Is the problem faced by a person with Broca's aphasia in generating nouns caused by knowing the concept to be expressed but not being able to find the correct verbal phrase in memory or is it caused by a defect in the semantic concept, or meaning in order to produce a verbal response. If it is the former, then cuing with text would suffice. If it is the latter, then cuing with symbols would be needed. There is the possibility that both text and symbols would be required. From a engineering design basis, knowing what type of cuing is necessary, significantly effects the boundaries of a design.

The approach: A group of five individuals with known diagnoses of Broca's aphasia volunteered for this study. They were all mature male adults who had suffered a stroke, gone through rehabilitation, and had reached their maximum potential through therapy. Prior to their stroke all were capable communicators with the english language.

Each were tested using three types of cues: pictures, text, and combined pictures/text. The response to no-cue was used as a control. A test involved verbally presenting a series of statements which needed to be verbally completed by the subject using a common noun. Nouns were chosen as they are the most readily illustrated concepts. Two hundred statements covering the categories of clothing, food and drink, local places, and household objects were used. There were 50 different sentences in each category. Typical sentences were: I can't take your picture today because I broke my _____; Perry Como made a lot of hit _____; I used to love to read a good _____; Bill lost a lot of money playing _____; She couldn't keep track of time after she broke her _____. The sentences were from a cuing set the subjects had previous been exposed to. This significantly reduced learning during testing as a factor in determining subject response.

The subjects were individually tested in an isolated room. In attendance was a speech therapist they were familiar with. The sentences were computer speech generated from a data set using Dec Talk's Perfect Paul voice. Each data set consisted of 50 statements randomly selected from all four categories. Each subject was tested four separate times, once for each cue, and once for the control. The order of cuing was also randomized. Ten seconds were allowed for the subject's response. When an appropriate response was given within the time limit, the therapists would press a key on the computer keyboard. The computer kept a log of the cuing method being used, the sentences being used, the subject response time per sentence, and which subject was being tested. After the therapists had pressed a key or the time limit had occurred the next sentence was provided.

For the three cuing tests, each cue was provided on a computer monitor, using VGA resolution, immediately after the sentence was given. For text, the cue was the desired noun, i.e. Book. For pictures, the cue was a grey scale image, obtained by digitally scanning a photograph, which illustrated the desired noun, i.e. a picture of a book. Both were provided for the cue which involved both text and pictures. The test with no-cue simply provided the sentences and waited ten seconds for the response.

Statistical methods: The experiment used a repeated-measure, within-subject factorial design. The independent variable of interest was the type of cues (text, picture, picture and text, and no-cue). The other two independent variables were the subject and the test session. The subjects were tested under all four types of cuing conditions. Repeated measures of subject performance were obtained in two sessions.

The time and content of subject response to each sentence were recorded on the computer. For each cuing condition within a session, the percentage of subject's responses to fifty sentences was calculated, and the average time of subject response to fifty sentences was also calculated. The dependent variables were the percentage of correct responses and the average time of subject response.

RESULTS

It was found that prior to any testing each sentence had to be carefully structured to assure that what the speech algorithm generated was correctly spoken english. This was done by modifying text spelling and punctuation. An adjustment process was also required to the scanned pictures to adjust contrast and detail. During testing, the subjects experienced no difficulties. The computer generated speech was easily understood as was the visual presentations on the computer monitor.

Analysis of variance on the percentage of correct responses and response time was performed using the subject, session, and cue type as the three independent variables. For the percentage of correct responses, the effect of session was not significant [F(4, 30) = 1.02), p = 0.3203]. The effect of subject was significant [F(4, 30) = 25.90, p = 0.0001] indicating individual differences. There was a significant effect of cues [f(3, 30) = 20.28, p = 0.0001]. A SAS Duncan analysis of this cue effect indicated that the picture-text combined cue yielded better responses of the subjects that the picture-only cue, and that the no-cue condition yielded worse performance of the subjects than any of the other cues. The text-only cue appeared better than the picture-only cue. However, this difference was not significant.

For the response time, there were significant effects of cue [F(3,30) = 17.22, p = 0.001]. The effect of session was not significant [F(1, 30) = 0.38, p = 0.5397]. A Duncan analysis of the cue effect indicated that both the text only and picture-text cues yielded better response time of the subjects than the picture only cue and the no-cue, and that the picture only cue was better than the no-cue. In general, the cue type had a significant effect on subject performance.

DISCUSSION

These results show that cuing with text for speech production of nouns is apparently sufficient for individuals with Broca's aphasia. Comparison of subject response time between text cues alone and text with pictures cues shows that the pictures add nothing to the cue. In addition, cuing with just pictures was not as good as simple text. From this it can be concluded that the test subjects were having difficulty finding the correct verbal phrase in memory in production of nouns.

One should be careful not to discount the use of a richer information set such as pictures or text with pictures for other types of speech cuing such as verbs. It has yet to be shown that action cuing can be just as effective with text. The results indicated the just considering the type of cue and not the subject response time to a cue does not give text an advantage over pictures.

REFERENCES

Cole, E., "Prosthetic Software for Individuals with Mild Traumatic Brain Injury: A Case Study of Client and Therapists," Proceedings RESNA '92 Annual Conference, vol 12, pp. 170-172.

Cole, E., et. al., "Design Parameters and Outcomes for Cognitive Prosthetic Software with Brain Injury Patients," Proceedings RESNA '93 Annual Conference, vol 13, pp. 426-428.

Friedman, M.B., "A Wearable Computer that Gives Context-Sensitive Verbal Guidance to People with Memory or Attention Impairments, Proceedings RESNA '93 Annual Conference, vol 13, pp. 199-201.

Kirsch, N.L., S.P. Levine, & H.M. Horstmann, "The Effect of Cognitive Impairment on Performance with Assistive Technologies," Proceedings RESNA '92 Annual Conference, vol 12, pp. 165-167.

Rosenek, J.C., et. al.,(1989), Aphasia: A clinical approach, Boston: College Hill

Vanderheiden, G.C. & C.J. Cress, (1992), "Applications of Artificial Intelligence to the Needs of Persons with Cognitive Impairments: The Companion Aid," Proceedings RESNA '92 Annual Conference, vol 12, pp. 388-390.

ACKNOWLEDGMENTS

This study was supported in part through a Pruit Seed Grant #550633, Office of Geriatric Medicine & Gerontology, Wright State University, Dayton, Ohio 45435.

Blair A. Rowley, Ph.D., P.E., C.C.E.
Biomedical and Human Factors Department
Wright State University
Dayton, Ohio 45453
(513) 873-5073 Office
(513) 873-5009 FAX
e-mail: browley@matrix.wright.edu

* Nong Ye, Ph.D. is currently with the Department of Mechanical Engineering, University of Illinois at Chicago

DEVELOPMENT OF AN INTERFACE TO ENHANCE MOBILITY FOR PERSONS WITH NEGLECT

Sara L.N. Chen-Wing and Geoffrey R. Fernie
Centre for Studies in Aging, Sunnybrook Health Science Centre
Institute of Biomedical Engineering, University of Toronto, Canada

ABSTRACT

The objective is to develop a control interface that will allow safe use of powered wheelchairs by persons with hemi-spatial neglect. The envisioned device will encourage the user to scan the neglected field so as not to miss hazards and to find targets. A graphical computer simulation was created and a cardboard model of the test environment was built as tools to assist in the first step in the development of the strategy. These tools were used to obtain feedback from four experts in the field of neglect in order to refine the strategy. The tools were found to facilitate feedback, resulting in suggestions and cautions for refinement of the strategy.

BACKGROUND

Of the estimated 50,000 Canadians who suffer a stroke each year, as many as 52% may exhibit neglect. Individuals with neglect syndrome fail to respond to meaningful stimuli on the side opposite their brain lesion. The cause of this lack of response cannot be attributed to a sensory or motor defect. Hemi-spatial neglect is more frequent, more persistent, and more severe with right-sided lesions than with left-sided lesions. Persons with a right hemisphere lesion who exhibit neglect will be the focus of this research.

Decreased mobility is a common sequela of stroke, affecting up to 58%[1]. Many of these people (15-20% of stroke patients) use manual wheelchairs--their unaffected hand and foot are used for propulsion and steering[2]. The impact of hemi-spatial neglect on wheelchair navigation has been investigated. Right hemisphere stroke patients with hemi-spatial neglect were found to strike more objects on their left than on their right; they also ran directly into obstacles placed in their path[3]. Owing to safety considerations, patients with hemi-spatial neglect are often not prescribed powered wheelchairs.

The consequences of neglect are not just hazards of collision--there are also missed opportunities. Neglected sensory information leads to impaired navigation, and less awareness of the environment. It is believed that enabling powered mobility for these people will be beneficial[4].

It is possible to train patients who suffer from hemi-inattention due to right hemisphere lesions to compensate for their problems. This can be done by: 1. making the individual aware of the problem, 2. forcing him/her to view stimuli systematically, and 3. repeating the procedure until it becomes automatic[5].

RESEARCH QUESTIONS

The ultimate goal is to develop an interface which will enable safe powered mobility for persons with hemi-spatial neglect. Stages in developing the interface strategy are outlined as follows: simulation of the initial strategy and proposed experimental design; use of the simulations as tools to obtain feedback from experts regarding the strategy; implementation of refinements and revisions; simulation of neglect in healthy subjects and testing the effect of the interface strategy on powered wheelchair driving ability; implementation of refinements; and, finally, use of subjects with neglect syndrome to test the evolved strategy in a controlled environment.

This paper will cover the first stages in the interface development. The objectives at this stage were:

1. to communicate the proposed strategy and to facilitate critical feedback from experts in the field of hemi-spatial neglect.
2. to interpret the expert feedback for improvement of the strategy.

METHOD

Stage One: Design of Test Environment & Interface; Construction of Communication Tools

The proposed test environment consists of a rectangular hallway with randomly placed doorways and obstacles; the random placement will prevent the subject from learning a route. As the user progresses along the hallway in a counter-clockwise manner, doorways are presented on the neglected side (left side in our case). In addition, barriers or obstructions which narrowed the hallway are placed randomly. To enhance the understanding of the physical structure in three dimensions, a cardboard model of this experimental environment was constructed.

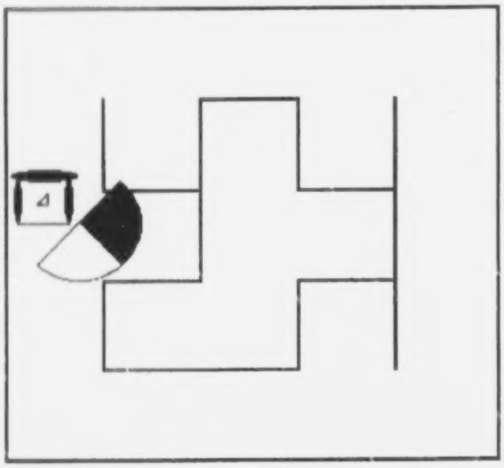


Figure 1: Graphics used for development of the interface strategy

A graphics program was written in QuickBASIC to convey the proposed interface strategy. The random maze was simulated as an aerial view (similar to early computer games). Using a joypad, the simulated subject (icon) navigates around the maze. As shown in Figure 1, the icon consists of the top view of a wheelchair with a nose (triangle) indicating the orientation of the user's head. A 180 degree field of view is indicated with the neglected portion being shaded. Using the joypad, the user can rotate the chair in either direction, and rotate the head 90 degrees left or right with respect to the chair.

The interface strategy aims to make the subject aware of what s/he is neglecting so that s/he will be able to avoid hazards and discover targets. The initial strategy implemented in the simulation uses an auditory tone to prompt the user to look to the left if a time has passed or a distance has been travelled. If the user turns his/her head to the left, he/she is rewarded with an upbeat noise. If the user has not turned sufficiently (to scan the entire field) to the left after a response interval, another stimulus of increasing intensity is provided. If the second stimulus generates no scan response by the end of response interval, then movement of the wheelchair is no longer permitted in order to ensure safety. Backwards motion is limited in both speed and distance. Detail of the initial strategy is outlined in Figure 2.

SCAN: turn the head beyond a threshold angle matched to the extent of neglect
TIME: maximum time between scan and stimulus
DISTANCE: maximum distance which can be travelled before scan is required
STIMULUS: prompt reminding the user to look left

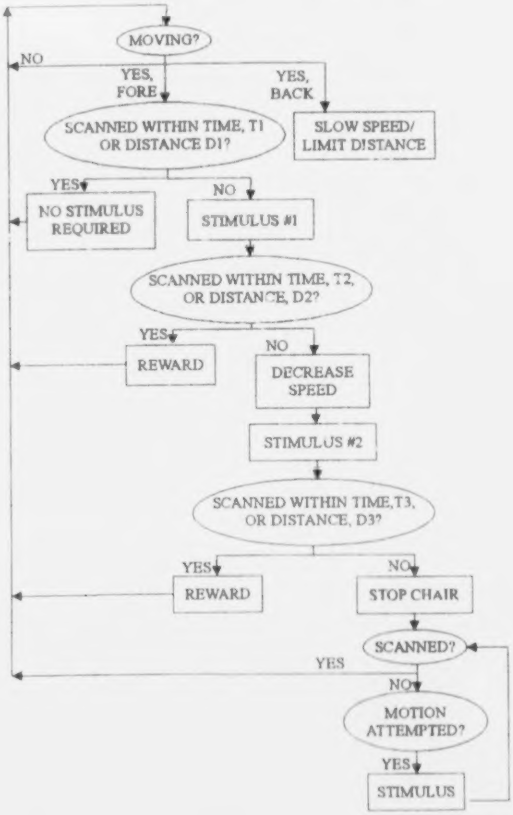


Figure 2: FLow chart of the original interface strategy.

Stage Two: Evaluation of Feedback from Experts

Feedback from four experts (professionals who work with neglect patients and have a good understanding of the phenomenon) was obtained. This was done in four steps: 1. using the two communication tools, the test environment was explained, as was the interface strategy; 2. the experts were then given the opportunity to interact with the communication devices until they understood the strategy and the proposed test environment; 3. structured questions were asked to elicit feedback and the session was videotaped; 4. using the videotapes, the qualitative information provided, was transcribed and coded.

RESULTS

The tools developed for communication proved effective. Judging from the response it generated, the cardboard model gave the experts a clear picture of the test environment. Problems with the simulation were: difficulty in relating to something like a computer game, the problem of scaling the distances before a scan was required, and the stimuli presented by the computer were found to be irritating. On the other hand, the annoying stimuli evoked discussion into the types of stimuli which could be used for the interface.

Suggestions provided: (number of experts)
- The strategy of reminding and ensuring the user look left before progressing would be an effective means of enabling the user to notice more of their surroundings (4).
- Auditory prompts (hearing is least affected by stroke) would be the best form of stimuli, with a tactile stimuli (vibrating) used as a back-up (3).
- Voice commands would be preferable as they avoid the necessity of teaching an association between a generic stimulus and the action of looking left (2).
- The frequency of prompts must be infrequent enough so as not to be annoying, but frequent enough that it will teach the user to reflexively scan (1).
- A motivational component should be built in somehow; the strategy must be user friendly, and warm. It is important that the user has input into setting parameters of function, thus maximizing use of any remaining cognitive ability (2).
- In some cases of the neglect syndrome, the patient's eyes are deviated to the location of their lesion and turning the head may not be sufficient (2).

DISCUSSION

It would be unethical to expose confused people to the multitude of strategy variations and the repeated trials required for development of an interface. Further confusion and frustration of these patients would not be appropriate. For these reasons, experts will continue to be used until we are reasonably confident that a viable strategy has been developed.

Virtual reality systems were considered for the simulation. Although this technology would provide the expert with a more realistic simulation, it is not yet cost effective for this application. A simple simulation tool was used in order to balance the development cost with the benefit gained.

The structure of the experimental environment (maze) discussed will be revised for the subject trials. Use of the communication tools enabled experts to better understand the structure and design. The dynamic interaction served to assist brainstorming and development of ideas.

To further understand the perception of people with hemi-spatial neglect, interviews will be conducted with subjects who have recovered from this syndrome and can now compensate for any remaining deficit. The next phase of strategy development will be to implement the revised strategy in a powered chair, simulate neglect in healthy subjects, and test their navigation ability with the strategy in a controlled test environment (a full-sized maze constructed of light polystyrene foam panels which can be easily moved to randomize the maze).

REFERENCES

1. Collen PM, Wade DT. Residual mobility problems after stroke. International Disability Studies. 1991;13(1):12-15.
2. Goodwill CJ. Mobility for the disabled patient. International Rehabilitation Medicine. 1984;6(1):iii-iv.
3. Webster JS, Rapport LJ, Godlewski MC, Abadee PS. Effect of attentional bias to right space on wheelchair mobility. Journal of Clinical & Experimental Neuropsychology. 1994 Feb;16(1):129-137.
4. Personal Communication. Dr. Sandra Black, Cognitive Neurologist. Toronto, Ontario. January 12, 1995.
5. Diller L, Weinberg J. Hemi-inattention in rehabilitation: the evolution of a rational remediation program. In: Weinstein EA, Friedland RP, editors. Advances in Neurology, Vol. 18. New York:Raven Press, 1977:63-81.

ACKNOWLEDGEMENTS

This research was supported by the Natural Sciences and Engineering Research Council of Canada. We wish to acknowledge Pamela Holliday for reviewing this submission and providing suggestions and Dr. Sandra Black for her advice and assistance.

Sara Chen-Wing
M.A.Sc. Student
Centre for Studies in Aging
2075 Bayview Avenue
Toronto, Ontario, Canada, M4N 3M5
(416)480-5858

A NEW APPROACH FOR AUTOMATIC EVALUATION OF SPATIAL NEGLECTING

G.Abello[1], M.Cincera[1,2],M.Rabuffetti[1], V. Da Pieve[3], A.Pedotti[1,2] & R. Cardini[3]
1) Centro di Bioingegneria, Fondazione Pro Juventute 'Don Carlo Gnocchi' - Milano, Italy
2) Politecnico di Milano - Dept. of Bioengineering, Milano, Italy
3) Neurological Rehabilitation Dept., Fondazione Pro Juventute 'Don Carlo Gnocchi' - Milano, Italy

Abstract

The evaluation of cognitive disabilities arises the problem of introducing a quantitative analysis of the degree of the disability. In this study, we present a new quantitative approach which allows for an automatic analysis of cognitive disabilities related to spatial neglecting. To this purpose, a system for automatic 3-D analysis of the movement (ELITE) was used while subjects were performing a traditional test ('H test') used for spatial neglecting evaluation (2). Beside traditional outcome of 'H test' (that is, the sketch left by the patient on the paper), Elite system allows for a complete description of kinematics of pen movements during task execution. Ten normal subjects and ten subjects with different degree of frontal and parietal pathologies performed the test. Preliminary results show the possibility of defining new kinematic parameters which allow for the discrimination between the two groups and among different degrees of pathology. The major emphasis of the results is given to the amount and completeness of information about subject's performance when the proposed methodology is compared to the traditional one.

Background

Tests for evaluation of types and degree of cognitive disabilities are often used in clinic and rehabilitation (1). Actually, many of these tests, particularly the ones involving handwriting, present several limitations. In fact, the interpretation of the results is always affected by a personal and therefore subjective judgement by the clinician. Besides, traditional tests do not allow for recording of important information which would bring to a complete evaluation of the motor performance. This factor becomes even more critical when a criteria for the evaluation of the effectiveness of a rehabilitation program is requested.

In the case of clinical tests involving writing, the score of the test is given only on the basis of the sketch left by the subject on the paper. An important information is related to the spatio-temporal modalities of task execution (2).

It appears clearly that a new approach for quantitative analysis of the problem is needed. In particular, an automatic procedure for analysis of the motor performance which allows for an objective evaluation of the results of the traditional test and for the extraction of significative parameters otherwise not available is requested. For example, a big amount of information during handwriting is contained in the trajectory versus time of the pen tip (3), as well as in the movement of the hand and of the upper limb (4).

An exploratory study in this direction is presented in this paper. Results suggest that the use of the described methodology could bring to a better comprehension of the degree and the type of certain cognitive pathologies.

Objective

To present a new methodology for cognitive disabilities evaluation which is able to maintain the degree of information given by traditional tests, but allows for the definition and extraction of new spatio-temporal parameters important for an overall judgement of motor task during performance of the test.

Methods

Ten normal subjects (control group) and ten subjects affected by different degree of pathologies (frontal or parietal damage following anoxia or aneurysm) participated to the study. A common symptom of the pathologies considered is the spatial neglecting, resulting in a low or absent perception of the left side of the visual field. The traditional 'H test' show the pathological evidence through the fact that patient is not able to consider the left below corner of the paper used in the test.

Protocol consisted in the execution of the 'H test'. A paper containing six rows of letters is presented to the subject. While confortingly seating in front of a desk, the subject is asked to draw a circle around each 'H' on the paper using a normal pen. No instructions about spatio-temporal modalities of task execution are given to the subject.

the pen is instrumented via one passive marker displaced close to the pen tip. Marker movement is recorded by an ELITE system (6) with four TV cameras (sampling frequency 100 Hz) placed in front of the desk. the Elite system is able to reconstruct in real time the position of the marker centroid. Off-line elaboration allow for a complete kinematic analysis of pen tip movement.

Signal reconstruction consisted of two phases: the first, related to the instrumentation used, consisted of the calibration of the environment in order to identify the relationship between pen tip movement and test paper surface; the second is aiming to the identification of recognised H through methods of pattern recognition. False 'H' recognition were purged via an automatic comparison between the pattern identified and a pre-defined mask of the 'H' position on the paper. This did not constitute a limitation for our experiment, since the aspect of interest on which the text is focused is the identification of parameters related to the spatio-temporal strategies of identification of the 'H'.

Data analysis consisted of parameters extraction starting from pen tip movement: number and position of recognised 'H', time between two following letter recognition, 'searching strategies' on the paper (see results), partial exploration time of the different parts of the paper, average direction of the movement.

Results

Pen tip movement is well described by the marker attached to the pen. Validation of the methodology can be obtained directly via a comparison between the sketch by the patient on the paper and the pattern automatically identified. All 'H' marked by the subjects were correctly identified by the procedure.

Example of pre-elaborated data is shown in fig. 1. Recognised H are clearly identifiable from pen tip trajectory.

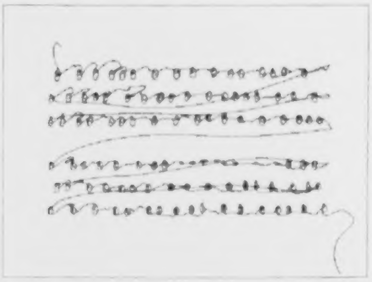
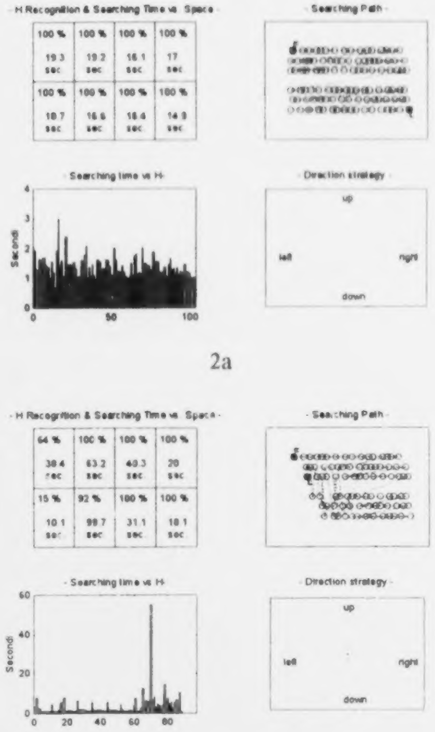


Fig.1 - Raw pen tip trajectory.

Examples of elaborated data for normal subject and subject with pathologies are reported in fig. 2a and 2b.



2a

2b

Fig.2 - Examples of data elaboration (a=normal subject; b=subject with anoxia)

For each figure: the top-left graph (representing the entire sheet) indicates the percentile of recognised 'H' and the searching time relative to each specific part of the paper when considering the sheet divided in two rows and four columns; the top-right graph (representing the entire sheet) indicates the path followed by the subject while identifying the 'H' (F=first identified; L=last identified); the bottom-left histogram reports the time (sec) between any H recognition and the following one; the bottom-right represents the count of displacement towards right, up, left and down (represented respectively as proportional oriented vectors 1,2,3 and 4) between any H recognition and the following one.

Normal subject shows a time and spatial independent behaviour, with a tidy 'searching strategy' (see Fig.2a top- right). Subject b, suffering from anoxia, shows: higher permanence time in the bottom left part of the paper; bigger time between

BEST COPY AVAILABLE

one recognition and the following, untidy 'searching strategies' (see Fig.2b top-right).

Discussion

When using traditional methodology involving handwriting (such as 'H test') for evaluating cognitive pathologies such as spatial neglecting, clinicians are able to judge subjects performance uniquely on the basis of the partial analysis of the sketch by the patients. Results reported in this study show that the use of a methodology which allows for automatic analysis of motor performance gives much more complete description of the spatio-temporal strategies used by each subject.

The methodology here proposed does not present, at least for the type of test considered, technical limitations due to problem in pattern recognition and identification. It must be said that similar performance and precision could be obtained using other techniques already used in handwriting analysis (for example, electromagnetic table devices (5)). However, these devices cannot be used for 3-D analysis and this constitutes a critical limitation, since extension of the methodology here reported to others text which could involve 3-D analysis is desirable.

The relevance of the differences depicted among subjects on the basis of the identified parameters allows both for discrimination among subjects and for quantification of degree of improvement along rehabilitation programs.

The data reported represent a partial elaboration of the raw data: new parameters could be defined and easily computed. This is of particular relevance, if one considers that even in our study subjects with different pathologies could be discriminated from normal subjects using different parameters.

The promising results obtained when considering the 'H test' suggest that the same methodology could be applied to other types of tests for cognitive pathologies evaluation.

References

1. Pizzamiglio L., et al. La rieducazione funzionale dell'eminattenzione spaziale. (Anna Basso & Sergio Carlomagno Eds.), Masson S.p.A. -Milano, 1990.
2. Thomas A.J.W.M., R.G.J. Meulenbroek & J.C.M. Tibosh. Latencies and kinematics reflect graphic production rules. Human Movement Science 10: 271-289, 1991.
3. Cincera, M., A. Campisi & M.Rabuffetti. Methodological aspects of kinematic analysis of pen movement during handwriting using the ELITE system. X Congress of the International Society of Electrophysiology and Kinesiology, Charleston, June 21-24, 1994.
4. Lacquaniti F., G. Ferrigno, A.Pedotti, J.F.Soechting & C.Terzuolo. Changes in spatial scale in drawing and handwriting: kinematic contributions by proximal and distal joints. Journal of Neuroscience, 7(3): 819-828, 1987.
5. Lacquaniti F., C.Terzuolo & P.Viviani. The law relating the kinematic and figural aspects of drawing movements. Acta Psychologica 54, 115-130, 1985.
6. Ferrigno G.C. & A. Pedotti. ELITE: a digital dedicated hardware system for movement analysis via real_time TV_signal processing. IEEE Trans Biomed Eng 32:943-950, 1985.

Abello Giuseppe
Centro di Bioingegneria
Fondazione Pro Juventute "Don C. Gnocchi"
20148 MILANO (ITALY)
Tel. (39)-(0)2-40308305
Fax. (39)-(0)2-26861144

DEVELOPMENT OF A COMPUTER SOFTWARE PROGRAM FOR PROCESS-BASED ASSESSMENT OF VISUAL PERCEPTION IN PERSONS WITH NEUROLOGICAL DISORDERS

Denise T. Reid, Jeffrey Jutai
University of Toronto, and Hugh MacMillan Rehabilitation Centre
Toronto, Ontario, CANADA

ABSTRACT

The Componential Assessment of Visual Perception (CAVP) (1) is a Windows™ based program designed for rehabilitation specialists working with clients from four years and older who have neurological disorders. Through visual search tasks, this version of the CAVP is capable of measuring the influence of specific cognitive processes (attention, visual memory, and visual discrimination) that affect a person's perception. Children and adults with neurological disorders have been identified as a group who have deficits associated with visual perception, which in turn interfere with normal function of activities of daily living, academic performance, and psychosocial activities. The CAVP will help us in better understanding the underlying nature of these deficits and help in suggesting appropriate remedial technologies. This paper will describe the CAVP. Ongoing and future research will be discussed.

BACKGROUND AND STATEMENT OF THE PROBLEM

Deficits associated with perceptual functioning are commonly observed in persons with head injuries, stroke, and congenital disorders such as cerebral palsy and spina bifida. The effective management of such deficits depends upon accurate and reliable assessment of the person's visual perceptual strengths and impairments. Traditional assessment tools fail to provide an exact appreciation of the processes operating that underlie a person's visual perceptual functioning through task performance. Instead, they indicate general functional deficits, for example, poor figure-ground ability. With this approach to assessment, global deficits are identified, but no consideration is given to the requirements of basic processes (cognitive and/or motor) that contribute to the area of deficit.

RATIONALE

The CAVP incorporates an information processing approach to the assessment of visual perception. It allows for an analysis of strategies of performance, therefore, enhancing opportunities for rehabilitation to build upon each client's strengths. Performance is viewed in terms of key processes visual attention, memory and discrimination, which operate interdependently and are believed to form the basis for all visual perceptual analyses (2).

The CAVP's computerized format offers several advantages: (a) precise control over visual stimulus and response environments, (b) objective recording of fine-grained variations in dependent measures, (c) interface technologies afford greater access for use with persons with physical disabilities allowing for less restrictive sampling, and (d) greater opportunity for concurrent measurement of psychophysiological variables relevant to assessment of emotional/motivational factors, fatigue, anxiety and eye movements.

DESIGN AND DEVELOPMENT

The structure of the CAVP comprises a Series and Matrix module of stimulus presentation. Each series module task consists of five featureally similar stimuli which are presented in a row. A single target stimulus must be identified (Fig 1).

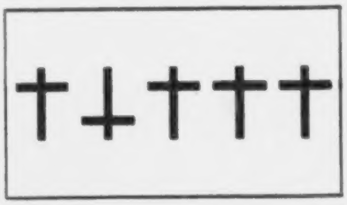


Figure 1. Example of Series Task Screen

The presentation of stimuli can be graded according to three levels of complexity. Stimuli range from simple to complex, the latter containing a greater number of attributes (parts and spatial dimensions). Within each level, tasks are designed to vary according to four types of featural modifications, ie., the stimulus itself is preserved with a spatial change made to it (Fig. 2). Thus, by manipulating the simulus complexity and modification within a level, it is possible to assess a wide range of visual discrimination processing skills. A Series report tracks each client's accuracy, time, and error patterns. The report is a visual record of client performance

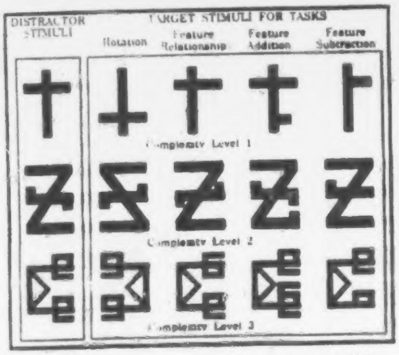


Figure 2. Complexity Levels and Modifications

The Matrix module tasks are designed to assess in a richer context, the cognitive processes of visual attention and visual memory. They consist of a 2-D array presentation of stimuli, allowing for a "cancellation task" protocol. Target stimuli are identified as a function of: (a) level of stimulus complexity, (b) number of targets, or (c) type of distraction environment.

In a low distraction environment, distractor stimuli differ in shape from target stimuli, whereas, in a high distraction environment distractor stimuli are similar to the targets, ie., same shape with attribute changes (Fig. 3 & 4).

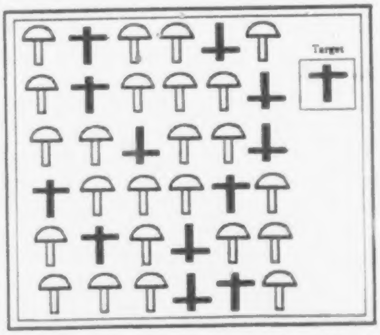


Figure 3. Level 1 Low Distraction Matrix Task

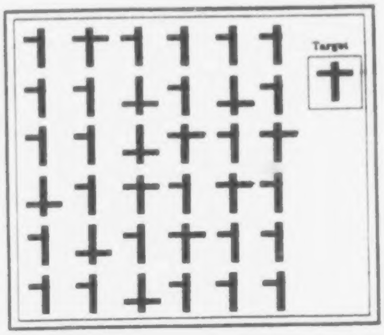
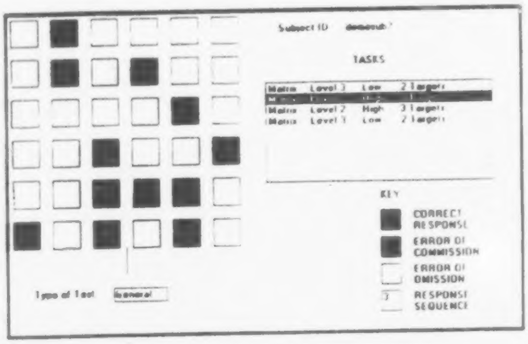


Figure 4. Level 1 High Distraction Matrix Task

Search and Matrix Tasks reports provide accuracy, timing, and scanning pattern information. The Search report (Fig. 5) allows the examiner to view the scanning strategies used by clients in either a general or split test presentation. In a general test the targets to be identified are randomly distributed over the matrix grid. The sequence in which the targets are chosen while performing the matrix tasks are represented on the search report by numbers located in each box which represent stimuli locations. Therefore, the numbers on the report starting with one and so on, represent the scanning approach used by clients, for example a top to bottom left to right strategy, etc. Boxes are color coded on the report to indicate a correct response (green), or incorrect responses, either errors of omission (yellow) or errors of commission (red). In a split test, an equal number of targets are distributed randomly on each side of the screen. The reason for this is to be able to monitor scanning strategies as well as whether a visual neglect problem exists. Individuals with lateralized brain injuries often show visual field disturbances.


Subject ID [illegible]

TASKS

Matrix Level 3 Low 2 Targets
[illegible]
Matrix Level 2 High 3 Targets
Matrix Level 3 Low 2 Targets

Type of Test General

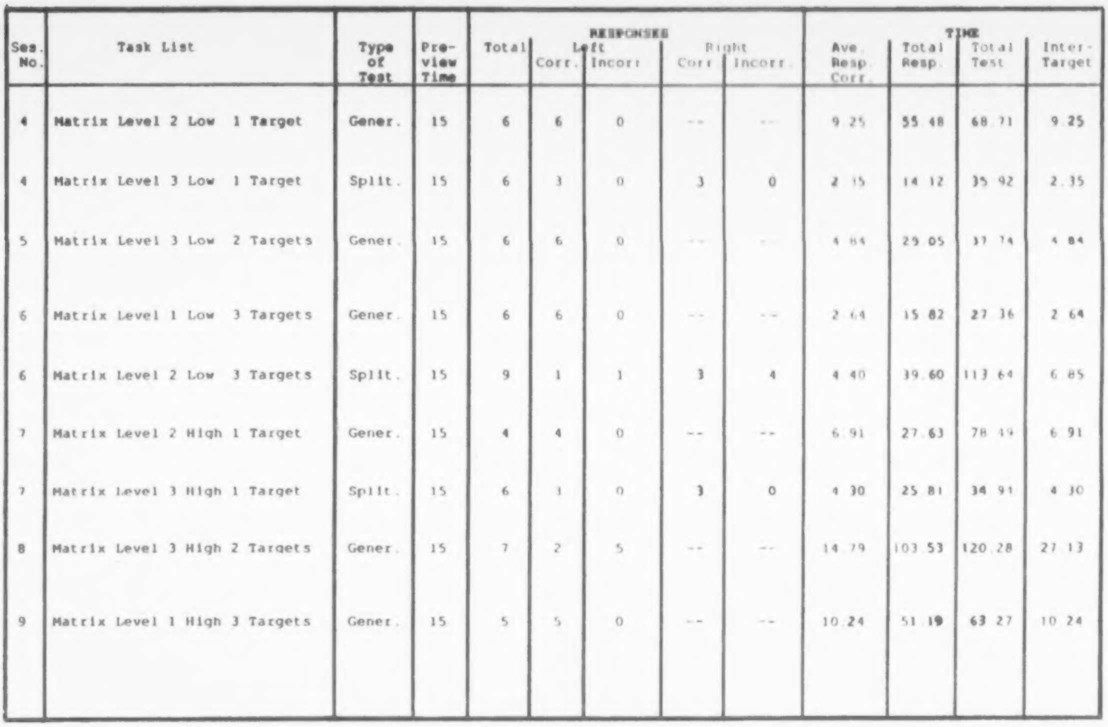
Figure 5. Search Report

The type of information collected in the Matrix Tasks report is presented in Figure 6. Clients can view their performance on selected matrix tasks with respect to timing and or accuracy information.

EVALUATION

Content validity of the CAVP has been established by selecting items based on empirical evidence that these types of stimulus items make demands upon distinctly different kinds of cognitive processes. Pilot studies suggest that the CAVP: (a) is sensitive to changes attributed to normal development, (b) discriminates between individuals with and without disabilities, (c) is easy to administer and can accomodate a wide range of physical (ie., motor) disabilities, and (d) is motivating to clients.

COPY AVAILABLE



Ses. No.	Task List	Type of Test	Pre-view Time	RESPONSES					TIME			
				Total	Left		Right		Ave. Resp. Corr.	Total Resp.	Total Test	Inter-Target
					Corr.	Incorr	Corr	Incorr.				
4	Matrix Level 2 Low 1 Target	Gener.	15	6	6	0	--	--	9.25	55.48	68.71	9.25
4	Matrix Level 3 Low 1 Target	Split.	15	6	3	0	3	0	2.35	14.12	35.92	2.35
5	Matrix Level 3 Low 2 Targets	Gener.	15	6	6	0	--	--	4.84	25.05	37.74	4.84
6	Matrix Level 1 Low 3 Targets	Gener.	15	6	6	0	--	--	2.64	15.82	27.36	2.64
6	Matrix Level 2 Low 3 Targets	Split.	15	9	1	1	3	4	4.40	39.60	113.64	6.85
7	Matrix Level 2 High 1 Target	Gener.	15	4	4	0	--	--	6.91	27.63	78.49	6.91
7	Matrix Level 3 High 1 Target	Split.	15	6	3	0	3	0	4.30	25.81	34.91	4.30
8	Matrix Level 3 High 2 Targets	Gener.	15	7	2	5	--	--	14.79	103.53	120.28	27.13
9	Matrix Level 1 High 3 Targets	Gener.	15	5	5	0	--	--	10.24	51.19	63.27	10.24

Figure 6. Matrix Tasks Report

DISCUSSION

An initial first step in our overall CAVP research program is to determine the basic measurement properties of this newly developed assessment tool. To start, its reliability is being evaluated with children, as well as its validity against a "gold standard" assessment tool. This is important in order to establish that the CAVP is at least as sensitive to variation in global visual perceptual abilities as determined by existing instruments. Future studies will examine the potential of the CAVP for other populations (adults with and without neurological disability), which will more fully describe the implications for remediation, and examine the relationships between the CAVP and activities of daily living. The latter will contribute to a better understanding of how the components of performance contribute to purposeful activity, and ultimately contribute to more precise prescriptions of assistive technologies and strategies for remediation of functional deficits.

REFERENCES

1. Reid, D.T. and Jutai, J. (1994). *The Componential Assessment of Visual Perception. Manual.* Department of Occupational Therapy, University of Toronto, Toronto, Ontario.

2. Ricciardione Todd, V. (1993). Visual Perceptual Frame of Reference: An Information Processing Approach. In P. Kramer and J. Hinjosa (Eds.), *Frames of reference for pediatric occupational therapy.* Baltimore, MD: Williams and Wilkins, (pp 177-232).

ACKNOWLEDGEMENTS

We acknowledge funding to date from the Easter Seal Research Institute, Ontario Ministry of Colleges and Universities, and the Ontario Rehabilitation Technology Consortium. We thank Microcomputer Science Centre Inc. for their commitment toward the future commercialization of the CAVP.

Denise T. Reid, Ph.D.
Associate Professor
Department of Occupational Therapy
University of Toronto, 256 McCaul St
Toronto, Ontario, CANADA M5T 1W5

Tel: (416) 978-5937 Fax: (416) 978-4363
Reid@medac.med.utoronto.ca

BEST COPY AVAILABLE

PSG-04
Rehabilitation Engineers

TRAINING TECHNICIANS FOR CAREERS IN REHABILITATION ENGINEERING TECHNOLOGY

Darlene G. Miller
Vermont Technical College
Randolph Center, Vermont U.S.A.

ABSTRACT

The United States currently faces a shortage of rehabilitation professionals with expertise in engineering technology (1). The need for rehabilitation engineering technicians, in particular, has been recognized in the wake of new legislation that ensures the civil rights of persons with disabilities and highlights a need for their improved access to rehabilitation services and assistive devices. Responding to this national need, Vermont Technical College (VTC) became the first educational institution in the country to offer an associates degree program in Rehabilitation Engineering Technology. The curriculum, which focuses on applied science, production, problem-solving and assistive technology modification, produces skilled technicians who can offer a range of specialized products and services to persons with disabilities. As an innovative program, VTC's Rehabilitation Engineering Technology (RET) program has gained national notice and sparked considerable interest.

BACKGROUND

Rehabilitation engineers and other rehabilitation professionals have long provided assistive technology to persons with disabilities (2). However, engineers alone cannot adequately provide all of the rehabilitation engineering services necessary to enhance the employability, education, communication, daily functioning, and recreational activities of persons with disabilities (1,2). A mix of engineers, technologists, and technicians is necessary (3). Engineers focus on research, design, and implementation of new technologies. Engineering technologists concern themselves with the practical application of commercially-available devices to meet the needs of the individual consumer. The work of the engineer and technologist is made much more effective by including a technician on the team. The technician is the team member who performs the modification to a commercially-available device, fits the device to the consumer, repairs the device, and works with other members of the rehabilitation team to train the consumer to use the device.

Therefore, for rehabilitation engineering personnel, the single most important factor that must be addressed with regard to educational programs is a recognition that a mix of rehabilitation engineers, technologists, and technicians is required (3). In 1992 Dolan identified nine graduate programs and one bachelors degree program which offer a degree with a focus in rehabilitation engineering. Only Vermont Technical College offers an Associates Degree in Engineering with emphasis in Rehabilitation Engineering Technology. This program is specifically designed to train skilled technicians to work as part of the rehabilitation team.

STATEMENT OF THE PROBLEM

Since VTC was the first college in the U.S. to offer such a program at the associates degree level, the development of the curriculum posed a challenge. To assist in the development of the program and its curriculum, VTC established an advisory committee. This committee was chosen to represent professional members of the rehabilitation team, rehabilitation engineers, and consumers of assistive technology.

The advisory committee strongly recommended that the program emphasize four objectives: that the curriculum provides students with a strong background in engineering technology, that students have frequent opportunities to interact with people who use assistive technology, that students participate in an internship, and that students complete a design project. Based on the recommendations of the committee and knowledge of RESNA's emphasis on quality assurance, the College developed an interdisciplinary program combining traditional courses in mechanical and electrical engineering, mathematics, physics, and language arts with specialized courses in assistive technology and disabilities.

APPROACH

Traditional Engineering Technology Component

To meet the committee's first objective: *to develop a curriculum that provides students with a strong background in engineering technology*, four traditional courses were chosen from mechanical engineering and electrical engineering technology. In *Manufacturing Processes*, the student is introduced to machine tools, measuring instruments, and machining operations and how they relate to the manufacturing process. The second course of the mechanical sequence, *Applied Mechanics*, emphasizes principles of statics and dynamics. In *Mechanisms*, the student acquires a thorough understanding of displacement, velocity, and acceleration characteristics of plane motion and the associated graphical and computer-aided methods of analysis. In the last course in the sequence, *Strength of Materials*, the student becomes familiar with stress analysis by studying coaxial and shear stress and strain, temperature relationships, torsion, shear and bending moments, beam stresses and deflections. All four of these courses serve as prerequisities to the specialized RET course, *Home and Mechanical Modifications*.

The electronics component of the RET program is intended to give students a good working knowledge of both digital and analog electronics and the ability to analyze and modify electrically controlled equipment. The first three electronics courses, *General Electronics I & II* and *Digital Systems*, introduce basic electronic components (resistors, capacitors, inductors, transformers, motors, generators, semiconductor devices, linear and digital integrated circuits, and a simple microprocessor) and the classic circuits in which they are found. These courses, with their associated labs, emphasize circuit analysis, circuit building, and testing. The final electronics course, *Electronic Applications*, introduces more complex, real world circuits (motor control, interrupt controlled microprocessor systems, communications circuits, etc.) which are important to the Rehabilitation Technician. All four of these courses serve as prerequisites to the specialized RET course, *Computer Modifications*.

To be certain that students have a strong background in drafting and CADD, two specialized engineering courses were developed: *Mechanical Drafting for Rehabilitation Technicians* and *Architectural Drafting for Rehabilitation Technicians*. In both of these courses, students are introduced to manual drafting equipment and Computer-Aided-Drafting software.

Specialized RET Courses

Three specialized RET courses were developed, one dealing with the psychosocial aspects of disability and two dealing with assistive technology and modifications. The curriculum was designed around four basic objectives: students should develop an expertise in assistive technology devices and their applications, gain an understanding of the human-technology interface, acquire an understanding of the role of the consumer in choosing an assistive device, and realize their role as a member of the rehabilitation team.

Disabilities Studies

The advisory committee felt that is was extremely important for students to have frequent opportunity to interact with the users of assistive technology. The committee also felt that it was important for the students to have an understanding of the most common disabilities and common issues relating to those disabilities. In *Disabilities Studies*, students are introduced to the disability rights movement, societal barriers, and misconceptions and stereotypes regarding persons with disabilities. Students are required to write a research paper and give an oral presentation on a disability. They are also required to write an analysis of a movie which features a person with a disability. This analysis requires the students to answer questions such as: is the portrayal positive or negative and does the movie perpetuate stereotypes and misconceptions? The highlight of the course is students have frequent opportunity to interact with guest speakers including consumers, rehabilitation professionals, and disability rights advocates.

Computer Modifications

In *Computer Modifications*, students acquire a working knowledge of computer and electric assistive technology devices. The students learn how to use and modify the device while simultaneously learning how persons with disabilities will benefit from the use of the technology. Students are exposed to both low and high technology devices and exposed to assistive technology for both PCs and MacIntosh computers. The highlight of the course is a design project, funded in part by the National Science Foundation. For this project, students are required to take commercially-available environmental control devices and computer assistive devices and combine them to create an integrated, accessible environment for a person with a disability. The goal of this project is to ensure that students are capable of performing a complete assessment, recommending a cost-effective solution, and choosing an appropriate assistive device that matches the consumer's abilities and preferences.

Home and Mechanical Modifications

The *Home and Mechanical Modifications* course discusses the philosophy and application of common environmental modifications for individuals with disabilities. Students apply learned concepts to varied topics including mobility, driving, architectural barriers, and recreation. Creative problem solving methods are introduced to help students apply assistive technology for individuals with disabilities. In the laboratory, students apply the learned principles of assistive technology. Some laboratory sessions will require students to design or fabricate modifications to meet the specific needs of an individual with a disability. Other laboratory meetings are "community-based," in which students have contact with people with disabilities to see how assistive technology affects the lives of these indivisuals.

Internship

The internship gives students additional practical experience. During the internship, students are exposed to most but not all of the following: persons with disabilities, the rehabilitation team, the various types of assistive technology and different persons with disabilities who use the technology, and the modification and repair of assistive devices. Students receive a stipend to complete the internship. This stipend is financed through a Rehabilitation Services Administration Long-Term Training Grant.

DISCUSSION

Technology for persons with disabilities has advanced past the gadgeteering of early days (4). Assistive devices are becoming more and more sophisticated and require the expertise of all types of rehabilitation engineering professionals. Therefore, when developing educational programs to train rehabilitation engineering professionals, it is important to recognize that a mix of engineers, technologists, and technicians is required to adequately ensure the delivery of services. Vermont Technical College's Rehabilitation Engineering Technology program, specifically developed to meet the growing demand for rehabilitation engineering professionals, trains technicians with the skills necessary to modify commercially-available devices, fit the device to the consumer, repair the device, and work with other members of the rehabilitation team to train the consumer to use the device.

REFERENCES

1. McQuistion, Linda (1992). Rehabilitation Technology: Engineering New Careers in Rehabilitation. American Rehabilitation, Summer, pp. 8-9, 34-35.
2. Galvin, Jan C. & McLaurin, Colin A. (1991, August/September). A History of Rehabilitation Engineering. REHAB Management, pp. 70-77.
3. Dolan, Frank A. (1992). Professional Education and Credentialing for Rehabilitation Engineering. Technology and Disability, 1(3), pp. 6-14.
4. Childress, Dudley. (1984, September). Rehabilitation Engineering. Mechanical Engineering, pp. 56-65.

ACKNOWLEDGEMENTS

Partial support for this work was provided by two sources, the U.S. Department of Education's Rehabilitation Services Administration Long-Term Training Program (grant number #H129V40002-94) and the National Science Foundation's Division of Undergraduate Education (grant number DUE - #9451447).

Darlene Miller, Associate Professor
Rehabilitation Engineering Technology
Vermont Technical College
Randolph Center, VT 05061
(802) 728-1345
dmiller@night.vtc.vsc.edu

Research Symposium
"Developments Toward a Direct Brain Interface to Control Assistive Technologies"

1995 RESNA Research Symposium

Sponsored by Prentke Romich Company

This year marks the establishment of an annual research symposium to be held each year at the RESNA Conference. While there have been a number of research symposia and special sessions held at the RESNA conferences over the years, no ongoing research forum has previously been established beyond the conference's regular scientific sessions. The goals of the annual RESNA Research Symposium include the development of an enhanced focus on scientific research at the RESNA conference, interchange between RESNA members and researchers from outside of RESNA whose work relates to assistive technology and rehabilitation engineering, and an opportunity to explore and discuss long term advancements in our field.

The 1995 Research Symposium, sponsored by Prentke Romich Company, explores recent accomplishments and current state of the art in the development of a direct brain interface to control assistive technologies. The concept of creating a direct interface to the brain has existed for many years. It is a concept quite commonly presented in science fiction as well as an active area of scientific research. Any method to interpret electrical brain activity for purposes of controlling assistive technologies could potentially benefit a wide range of people. For the persons with a locked-in syndrome, a brain interface could serve s a simple control mechanism for communication where non existed before. For the individual who uses a functional neuromuscular stimulation system to walk, it could provide improved function and coordination. In the distant future, a brain interface might conceivably be able to serve as the basis for a high speed synthesized speech system for a persons who cannot speak or an invisible transcription system for an office worker.

The papers which follow in this proceedings cover systems based on both surface and intracortical recordings. Recording techniques using silicon based micro-electrodes are also discussed. The papers include those from the morning didactic session with featured talks from Jonathan R Wolpaw MD, Wadsworth Center for Laboratories and Research, State University of New York; Donald R Humphrey PhD, Laboratory of Neurophysiology, Emory University School of Medicine; and William Heetderks MD PhD, Division of Fundamental Neuroscience, National Institutes of Health. Also included are 14 papers from two scientific paper sessions held in the afternoon. Together these papers represent a valuable resource which provide a good overview of past accomplishments, state of the art, the feasibility of various applications for people with severe disabilities, and the potential for future developments of direct brain interfaces.

On behalf of RESNA we would like to take this opportunity to express our appreciation to Barry Romich and the Prentke Romich Company for their support of the 1995 RESNA Research Symposium and the leadership it provides in establishing this annual event. It is very gratifying to work with a manufacturer who recognizes the importance of the more basic research efforts presented here in advancing the state of the art of augmentative communication and assistive technology interface systems.

We hope that this year's symposium sets a good example for the years to come and invite RESNA members (and others) to submit ideas for future research symposia to the Research Committee. In order to guarantee the continued success of the annual RESNA Research Symposium we need both these suggestions and the volunteer efforts of RESNA members.

Simon P. Levine, Ph.D.
Chair, 1995 RESNA Research Symposium

Donald R. McNeal, Ph.D.
Chair, RESNA Research Committee

DEVELOPMENT OF AN EEG-BASED BRAIN-COMPUTER INTERFACE (BCI)

Jonathan R. Wolpaw and Dennis J. McFarland
Wadsworth Center for Laboratories and Research
New York State Department of Health and State University of New York
Albany, New York

ABSTRACT

Those with neuromuscular disabilities often need alternative channels for communication and control. Until recently, alternatives have relied on remaining neuromuscular function, and thus have been of limited value for those with the most severe disabilities. EEG-based brain-computer interface (BCI) technology may provide these people with a new communication channel not dependent on neuromuscular function. In our BCI system, people learn to use specific components of the EEG to control cursor movement on a video screen in one or two dimensions. Our research goal is achievement of mouse-like cursor control so that BCI users can operate the many mouse-driven programs now available.

INTRODUCTION

The neuromuscular system provides the channels through which the brain normally communicates with and controls its environment. Those with severe neuromuscular impairments often require assistive technologies for communication and control. Available technologies rely in one fashion or another on remaining neuromuscular function. They may augment remaining capabilities, as when eye movements are used to communicate (1), or they may circumvent points of damage, as when electromyographic activity (EMG) from muscles above the level of a spinal cord lesion is used to control electrical stimulation of muscles below the level and thereby restore useful movement (2). Because these assistive technologies require some degree of muscle control, they may not serve those with the most severe disabilities, individuals who are in the advanced stages of amyotrophic lateral sclerosis (ALS) or have had massive brainstem strokes. These people may require a new communication channel that does not depend on neuromuscular function. Recent studies indicate that electroencephalographic (EEG) activity recorded from the scalp might serve as this new channel.

Because the EEG reflects the activity in the underlying brain, the brain's intentions should, in theory, be detectable in it. However, in practice, the resolution and reliability of the information detectable in the EEG is severely limited by the vast number of electrically active neuronal elements, the complex geometry of the brain and head, and the disconcerting trial-to-trial variability in brain operations. In response to these problems, current efforts to develop EEG-based brain-computer interface (BCI) technology have focused on identifying specific components of the EEG that can be easily recognized by computer and used for communication.

These BCI technologies fall into two classes. One class focuses on evoked potentials, EEG activity that is produced in response to specific stimuli. For example, Farwell and Donchin (3) measured the visual evoked potential (VEP) produced in response to flashing letters. They showed that the amplitude of the P300 peak of the VEP was larger in response to the letters the person wished to select, and thus could be used to communicate commands. The other class focuses on spontaneous components of the EEG, i.e., components that are not linked to specific external stimuli. They are identified by their frequencies and their locations on the scalp. Our studies have concentrated on training people to use such components recorded over sensorimotor cortex as a control signal (4-7). We began by training them to use the amplitude of the 8-12 Hz mu rhythm, and more recently have explored use of 18-24 Hz beta activity.

METHODOLOGY

Encouraging early efforts (4) led to the current development protocol, in which people learn to use the mu rhythm and/or other EEG components to control cursor movement on a video screen. We employ cursor movement as the output because it is objective, easily implemented, and readily quantified, serves as a prototype for a variety of prosthetic devices, and can be applied to operation of mouse-driven programs. Users, including some with significant neuromuscular disabilities (e.g., spinal cord injury or ALS) learn to use EEG to move a cursor from the center of a video screen to a target located on the periphery. In the one-dimensional mode, the targets are located at the top or bottom edge and the cursor moves vertically. In the two-dimensional mode, the targets are located anywhere on the periphery (e.g., one of the four corners) and the cursor moves both vertically and horizontally. EEG in specific frequency bands at specific scalp locations is assessed by on-line frequency analysis and translated into cursor movement. For example, in the one-dimensional mode, larger amplitudes of the 8-12 Hz mu rhythm recorded over sensorimotor cortex of one hemisphere move the cursor up and smaller amplitudes move it down. The function that translates these amplitudes into cursor movements is a linear equation the parameters of which are derived from evaluation of the user's previous performance. In the two-dimensional mode, one linear equation controls vertical cursor movement and another controls horizontal movement.

Users participate in 2-3 training sessions per week. Each session consists of 7-8 3-min runs separated by 1-2 min breaks. Each run consists of a series of 2-4 sec trials in each of which the cursor appears in the center of the user's video screen, a target appears somewhere on the periphery, and the cursor moves until it reaches the periphery. If it reaches the target a hit is registered, while if it reaches some other point on the periphery a miss is registered. In either case, after a brief pause the next trial begins.

RESULTS

One-dimensional control develops steadily over at least 4-6 weeks. Figure 1 shows the control developed by a user over amplitude in the 8-12 Hz band of EEG recorded over left sensorimotor cortex. When amplitude in this band is high, the cursor moves up, when it is low the cursor moves down. The user changes amplitude appropriately to hit top or bottom targets. His EEG control is focused in the 8-12 Hz frequency band. Figure 2 from another well-trained user displays the topographical distribution of this control, expressed as r^2, the percent of the total variance of amplitude in the frequency band that is accounted for by the target. Control is focused over sensorimotor cortex of the left hemisphere and a lesser focus is evident over the homologous area on the right side. Well-trained users can hit top and bottom targets with accuracies >90%.

Throughout study, we ask users about how they control the cursor. They report adopting various strategies, such as thinking about a certain activity (e.g., lifting weights) to move the cursor down, and thinking about relaxing, or about floating up, to move it up. As training progresses and performance improves, they tend to report that such imagery is no longer needed. Furthermore, we find that well-trained users can control the cursor while carrying on casual conversation or while performing mental arithmetic problems and giving the answers. Thus, EEG-based cursor control appears similar to more conventional skills which, once learned, no longer require intense concentration. This finding is important for eventual practical application of BCI technology.

Present efforts focus on further improving the accuracy and rate of cursor control. The principal approach is comprehensive frequency and topographical analysis of data gathered from 64 scalp locations during BCI operation. This analysis seeks to identify methods for improving the online algorithm that translates EEG into cursor movement. Improvements currently under study include use of an autoregressive spectral estimation algorithm rather than a Fourier transform-based spectral estimation algorithm for online frequency analysis, use of the common reference electrode rather than an ear reference or bipolar recording, and use of EEG from additional electrode locations.

In the course of this work, we are further developing the methods that enable users to control cursor movement in two dimensions. Initial encouragement for this effort came from studies of Pfurtscheller and his colleagues indicating that mu rhythm activity is composed of a number of components that may be distinguished by frequency and/or topography (8,9). These data suggested that users might learn to control several of these components independently and thereby control cursor movement in two dimensions. Our first study of two-dimensional control used two channels of bipolar EEG, one over sensorimotor cortex of each hemisphere, as shown in Figure 3. Figure 3 also illustrates the trial format for two-dimensional cursor control. The sum of mu rhythm amplitudes over the two hemispheres controlled vertical cursor movement and their difference controlled horizontal movements. Current studies are exploring control algorithms based on additional frequency bands and/or additional scalp locations.

The initial two-dimensional study (7) produced clear evidence that users can learn to use EEG to control two channels simultaneously. This is illustrated in Figure 4. It shows for one user the means and standard errors of the mu rhythm sums and differences associated with each of the four corner targets. The four points are significantly and appropriately different and do not lie on a single line, indicating that the user was controlling the sum and the difference independently and thereby moving the cursor to the corner target.

DISCUSSION

The accuracy and rate of current one-dimensional cursor control should be sufficient for a variety of single-switch devices used by those with severe motor disabilities, and we are beginning to address such applications. Two-dimensional control is still largely a laboratory phenomenon that must be improved in accuracy and rate before it can be of significant practical value. Current extensive frequency and topographical analysis of 64-channel EEG recorded during two-dimensional BCI operation is leading to improvements in user training and in the on-line algorithm that converts EEG into cursor movement. The ultimate goal is to achieve mouse-like control, so that EEG-based cursor movement can be used to operate the wide variety of mouse-driven programs presently available.

In the course of this work, we are attending to three important issues that necessarily confront any effort to develop EEG-based communication. The first is the need to ensure that the electrical activity recorded from the scalp and used for communication is actually EEG. A variety of non-EEG phenomena, including EMG from head and neck muscles, potentials generated by eye movements or blinks, and head movement artifacts may contribute to the electrical activity recorded from the scalp and masquerade as EEG. These contaminants can normally be distinguished from EEG by their frequency characteristics and/or topographical distributions. True mu rhythm control is confined to a narrow band near 10 Hz and focused over sensorimotor cortex (e.g., Figure 2). In contrast, EMG activity is very broad-banded, increases with frequency to a maximum above 100 Hz, and tends to be located near the periphery of the scalp; while eyeblink artifact is mainly low in frequency (i.e., 1-5 Hz) and is concentrated near the forehead. Such non-EEG phenomena, particularly EMG, may themselves provide bases for assistive communication technologies. However, in any effort to develop EEG-based communication, they are simply contaminants, and every effort must be made to insure that they do not interfere with the operation of BCI technology.

The second issue is the capacity of those with significant neuromuscular disabilities to learn EEG-based communication. Our experiences to date with a limited sample of individuals with multiple sclerosis, cerebral palsy, spinal cord injury, Friedrich's ataxia, or ALS suggest that they are as capable of mastering EEG-based cursor control as are non-disabled users. Most individuals, non-disabled or disabled, who can understand the task and see the screen can learn to control cursor movement to some degree. Furthermore, several considerations suggest that those with severe disabilities might be particularly successful. First, they probably have much greater incentive than monetary reward can usually engender in non-disabled users. Second, many of the most disabled individuals (e.g., "locked in," high cervical spinal cord transection, or late ALS) presumably have large areas of sensorimotor cortex that are no longer occupied by their normal functions and thus may be more capable of accommodating a new function.

The third issue arises because EEG-based communication profoundly changes the status of the EEG. By current understanding, EEG activity is only electrical noise produced by the brain in the course of its normal operations. It reflects brain function, but does not have a role in that function. BCI technology changes this normal situation. It converts the EEG into a new communication and control channel, a new brain output. The brain continually adjusts its conventional neuromuscular outputs based on their outcomes, it continually strives to improve performance. In similar fashion, EEG-based communication, whether using evoked potentials or spontaneous EEG, will inevitably engage the adaptive capabilities of the brain. Unless EEG-based communication is perfect from the start, which is not a realistic possibility, the brain can be expected to behave as it does during operation of its traditional neuromuscular outputs. It will adjust the output, in this case EEG, so as to improve performance. As a result, the function of any EEG-based BCI involves the interaction of two adaptive controllers: the computer system which is trying to translate the EEG as accurately as possible into an output (e.g., a cursor movement), and the user's brain which is trying to adjust the EEG so that the computer understands its wishes as accurately as possible. While this interaction will presumably be most complex and important when the user is first learning to operate the system, it will always be an important factor in BCI technology, as it is in operation of conventional neuromuscular outputs. The proper management of this interaction is perhaps the most important and difficult issue that must be addressed in development of BCI technology.

CONCLUSION

EEG-based brain-computer interface (BCI) technology could provide a new communication and control channel for those with severe neuromuscular disabilities. Continued development of BCI technology and realization of its promise depends on careful attention to the detection and elimination of non-EEG artifacts, on the capacities of specific user groups to master its use, and on recognition and constructive engagement of the brain's formidable and ubiquitous adaptive capacities.

REFERENCES

1 LaCourse, J.R. and Hludik Jr., F.C. (1990) An eye-movement communication system for the disabled. *IEEE Trans. Biomed. Engin.*, 37, 1215-1220.

2 Stein, R.B., Peckham, P.H., and Popović, D.B. (1992) *Neural Prostheses: Replacing Motor Function After Disease Or Disability*, New York: Oxford University Press.

3 Farwell, L. A. and Donchin, E. (1988) Talking off the top of your head: Toward a mental prothesis utilizing event-related brain potentials. *Electroencephalogr. clin. Neurophysiol.*, 70, 510-523.

4 Wolpaw, J.R. McFarland, D.J., and Cacace, A.T. (1986) Preliminary studies for a direct brain-to-computer parallel interface. *Projects For Persons With Disabilities*, IBM Technical Symposium, 11-20.

5 Wolpaw, J. R., McFarland, D. J., Neat, G. W. and Forneris, C. A. (1991) An EEG-based brain-computer interface for cursor control. *Electroencephalogr. clin. Neurophysiol.*, 78, 252-259.

6 McFarland, D. J., Neat, G. W., Read, R. F. and Wolpaw, J. R. (1993) An EEG-based method for graded cursor control. *Psychobiol.*, 21, 77-81.

7 Wolpaw, J. R. and McFarland, D. J. (1994) Multichannel EEG-based brain-computer communication. *Electroencephalogr. clin. Neurophysiol.*, 90, 444-449.

8 Pfurtscheller, G. Functional topography during sensorimotor activation studied with event-related desynchronization mapping. *J. Clin. Neurophysiol.* 6: 75-84 (1989).

9 Pfurtscheller, G. and Berghold, A. Patterns of cortical activation during planning of voluntary movement. *Electroencephalogr. clin. Neurophysiol.* 72: 250-258 (1989).

10 Sharbrough, F., Chatrian, G. E., Lesser, R. P., Luders, H., Nuwer, M. and Picton, T. W. (1991) American Electroencephalographic Society guidelines for standard electrode position nomenclature. *J. Clin. Neurophysiol.* 8: 200-202.

ACKNOWLEDGEMENTS

The work reviewed here was supported in part by IBM Corporation, the New York State Science and Technology Foundation, and the National Center for Medical Rehabilitation Research, NICHD, NIH (HD30146).

Jonathan R. Wolpaw
Wadsworth Laboratories
New York State Dept. of Health
Box 509, Empire State Plaza
Albany, NY 12201-0509 USA
Phone 518-473-3631
Fax 518-486-4910
e-mail wolpaw@wadsworth.org

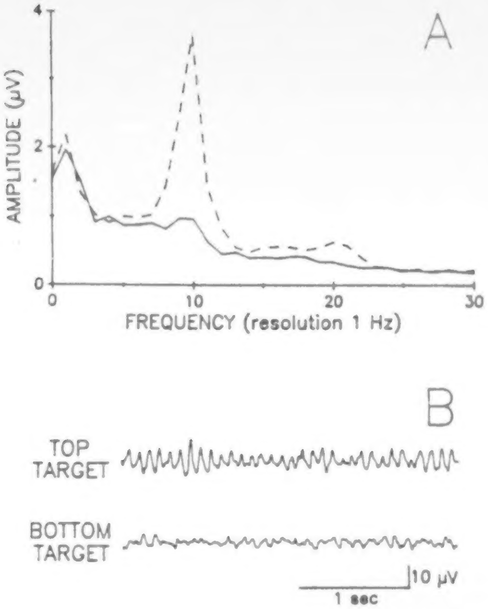


Figure 1: A: Frequency spectra of a user when the target is at the bottom (solid) and at the top (dashed). The main difference between the two spectra is in the mu rhythm peak. Differences at other frequencies are absent or minimal. B: Sample EEG traces over sensorimotor cortex of this user during trials with a top or bottom target. The mu rhythm is prominent with the top target, and minimal with the bottom target. (From 5.)

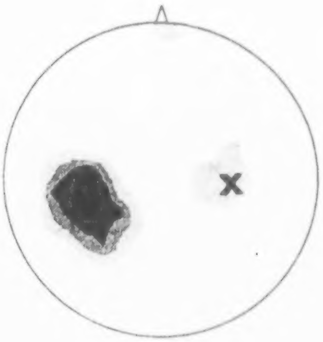


Figure 2. Average r^2 at 12 Hz for a well-trained user who was controlling vertical cursor movement with mu rhythm activity over sensorimotor cortex. The head is viewed from above. The nose is at the top. The lightest level is below 0.11 and the darkest is at least 0.27. The centers of right and left sensorimotor cortices are indicated by the x's. Control is focused over the left sensorimotor cortex. (See text for further explanation.)

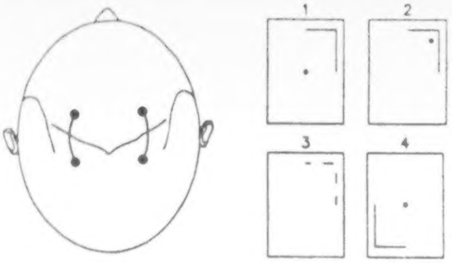


Figure 3: Left: The bipolar channels used to control two-dimensional cursor movement (Figure adapted from 10). Right: The video screen seen by the user. 1: The trial begins with the cursor in the center of the screen and the target in one of the four corners. 2: The cursor, controlled by the user's mu rhythm amplitudes over right and left hemispheres, moves toward the target. 3: When the cursor hits the target, the target flashes. (If it reaches a non-target point on the periphery of the screen instead, an error is registered.) 4: After a brief pause, the cursor reappears in the center of screen and a new target appears. (From 7.)

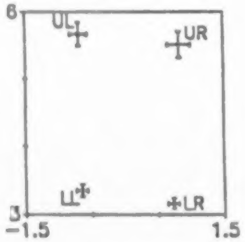


Figure 4: Mean (± standard error) of the sums of right and left mu rhythm amplitudes (ordinate; μV) versus mean (± standard error) of their differences (abscissa; μV) for each of the four corner targets (i.e., upper left (UL), upper right (UR), lower left (LL), lower right (LR)) for one well-trained user. As indicated in the text, the sums controlled vertical cursor movement, and the differences controlled horizontal cursor movment. The four points are significantly and appropriately different and do not fall on a single line. Thus the user was controlling two EEG channels independently. (From 7.)

INTRACORTICAL RECORDING OF BRAIN ACTIVITY FOR CONTROL OF LIMB PROSTHESES

Donald R. Humphrey and Leigh R. Hochberg
Laboratory of Neurophysiology, Emory University School of Medicine
Atlanta, GA

ABSTRACT

Evidence is reviewed from neurophysiological studies of the motor cortex in primates in relation to the question of whether signals derived directly from this and similar regions of the brain might be used for control of assistive devices.

HISTORICAL BACKGROUND

The concept of using signals derived directly from the brain to control prosthetic devices gained impetus in the late 1960s. Researchers in rehabilitation medicine had suggested that electromyographic (EMG) potentials from non-paralyzed muscles might be useful for the control of artificial limbs (1). At about this same time, neurophysiologists were developing techniques for recording the discharge of neurons in the brains of alert, subhuman primates performing learned movements (2).

Stimulated by these seemingly unrelated lines of research, Dr. Karl Frank, an eminent scientist at the National Institute of Neurological Diseases and Stroke (NINDS), reasoned that techniques might be developed for safe, long-term recording from neurons within the human brain. If so, signals derived directly from cells in the motor control regions of the brain could then be used to control either movements of artificial limbs or movements produced by direct electrical stimulation of paralyzed muscles. To pursue this goal, he established the Laboratory of Neural Control within the NINDS in 1968, and the extramural, Neural Prosthesis (NP) Program in the early 1970s. A major goal of both was the application of neurophysiological and electrical engineering methods to rehabilitation medicine: specifically, the development of neurally controlled prostheses for paralyzed persons. Frank also envisioned prostheses for certain deaf or blind persons, consisting of sensor-controlled stimulation of appropriate auditory or visual centers in the brain.

Through Frank's laboratory and projects funded by the NP Program, the field of neural prosthetics gained momentum. These efforts were subsequently sustained and expanded by Drs. F.T. Hambrecht and W. Heetderks, the current directors of the NP Program. The Program now supports neural prosthetic research at laboratories both in the U.S. and abroad, research that is leading to technical innovations that will advance neural prosthetics and related areas of basic neuroscience for decades to come. An early history of the development of this field may be found elsewhere (3).

SELECTING SITES FOR THE DERIVATION OF CONTROL SIGNALS

It is not a "given", however, that signals derived directly from the brain will in all or even many cases be the most desirable for prosthesis control, particularly when less invasive options are available. For example, small, voluntary movements about the shoulder have been used to control electrical stimulation of paralyzed muscles in the forearm and hand of patients with cervical spinal cord injuries, thus restoring some useful movements of the hand (4). Also, EMG signals from muscles of the upper arm and shoulder have been used to control artificial hands for amputees. Examples of this type and excellent discussions of the problems involved in the myolectric control of prostheses are provided by Stein *et al.* (5). The success in using such signals for "non-natural" purposes is a vivid illustration of the "plasticity" of the brain in neuromuscular control; i.e., of how readily it learns to modify the signals sent to a set of muscles so that their activities become appropriate for a new task. Further, at the current state of the art, the ease and lower risk in deriving EMGs makes their use clearly preferable to any attempt to derive control signals directly from the brain.

Then why persist in research aimed at these attempts? There are several reasons. First, useful EMG signals may not in some cases be available: for example, in patients with injury to the high cervical spinal cord. Second, if technical problems can be overcome, the "richness" with which the body musculature and the parameters of movement are represented in circumscribed, accessible regions of the brain, makes the derivation of signals from them theoretically attractive. For example, the areas of the cerebral cortex that normally control voluntary movements of the arm and hand are thought to be *comparatively* intact after spinal injury, as is the contractile apparatus of paralyzed muscles; the primary deficit is an interruption of the spinal pathways which connect brain and muscle. Might not it be possible, then, to *artificially* reconnect them; i.e., to record signals directly from motor control regions of the cortex, process them as required, and use them to control movements produced by direct, electrical stimulation of paralyzed muscles? Additionally, would not signals from brain areas that would normally control a set of (now-paralyzed) muscles be more natural for such control than EMG signals derived from other muscles? Though changes are known to occur in brain and muscle after spinal cord injury that make the answers to these questions more complex than they first appear, the presumed answers are nonetheless part of the rationale that motivates researchers in this field.

ARM-HAND AREAS OF THE CEREBRAL CORTEX

The cerebral cortex of each hemisphere in primates contains several areas that are involved in voluntary control of the arm and hand. The locations of these regions in the macaque brain are shown in Figure 1. These areas are extensively interconnected. In addition, each gives rise to pathways (corticospinal, cortico-bulbo-spinal) to the spinal centers that organize and drive muscle activity in the arm. Not all of these areas however, are involved in controlling arm-hand movements at all times; instead, the active subset appears to depend on the behavioral context in which an arm-hand movement occurs.

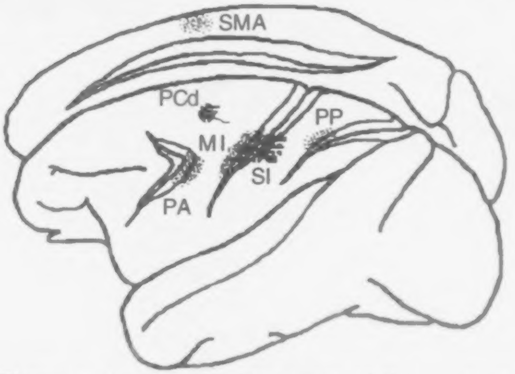


Figure 1. Arm-hand motor areas of the cerebral cortex. The locations of six of these areas (dotted regions) are shown on a drawing of the macaque monkey cerebral cortex. The drawing shows the lateral surface and a mirror-image of the medial surface of one cerebral hemisphere. Major sulci are drawn partly open, to show the extensions of the arm-hand regions into their depths. Abbreviations: PA= postarcuate, PCd=precentral dimple, MI=precentral, SI=somatosensory, PP=posterior parietal, and SMA =supplementary motor areas. Adapted from Humphrey and Tanji (7).

For example, electrical stimulation of cells in the postarcuate area (PA in Figure 1) may evoke hand movements. Yet, neurons in this area appear to discharge in relation to movements of the contralateral hand only if it is brought toward the face for oral exploration of an object, or for ingesting food (6). Movement-related cells in other regions may show more or less context dependence. In addition, the areas differ in their responsiveness to visual and auditory stimuli, and in the nature of the "commands" that they appear to issue in generating and controlling movement; detailed discussions of these differences may be found elsewhere (7). The important point here is that the optimal site(s) for deriving prosthesis control signals may be any one or even a combination of several of these regions, depending on the control parameters that are required, and the importance of visual and auditory feedback.

All of these cortical sites are surgically accessible, in particular those more lateral in the hemisphere. At present, however, most is known about the properties of the precentral (MI) motor area. Moreover, cells in this region normally participate in the control of *all* voluntary movements of the arm and hand, regardless of the behavioral context in which they occur. For these reasons, it is currently a preferred site for research on the use of brain signals for motor prosthesis control.

Topographic Organization of the Precentral Motor Cortex

The brain region from which control signals are to be derived should ideally contain a topographic representation of the muscles to be controlled, or of the fundamental movements to be produced. By "topographic", we mean that neurons in a particular zone are related primarily to control of a particular muscle, a small set of functionally linked muscles, or a simple movement. While zones with different motor functions can overlap, it is best if they are partially separate, thus comprising a map of the motor periphery with identifiable topography. This requirement is necessary, of course, for optimal placement of recording electrodes into regions which are known to control particular muscles or movements.

The precentral gyrus of primates, often referred to as the *primary* or *M I* motor cortex, meets this requirement. The organization of MI has been studied extensively with electrical stimulation methods, with the features revealed depending in part on the methods used; reviews of this history may be found elsewhere (8). Here, we need only summarize evidence from recent studies with unanesthetized primates, in which the motor cortex has been mapped with stimulating microelectrodes, and with observations of both evoked movements and EMG activity (7-11). These studies support the following generalizations.

(1) With respect to evoked *movements*, the arm-hand region of MI has a rough topographic organization. Regions which control movements about the shoulder, elbow, wrist, or of the digits, overlap; moreover, there are multiple sites from which movements about a particular joint can be evoked. However, the overlap between these zones is not complete.

(2) When the evoked activity of single *muscles* is observed, this topography changes. Single muscles are "represented" at, i.e., may be activated from, many more sites in MI than the evoked movement maps suggest. These sites are not, however, distributed randomly. Our studies have shown that, when the maps for muscles acting at different joints along the arm are superimposed, they congregate in what appear to be three to four complete maps of the major muscles of the arm. These representations appear as rostrocaudally oriented bands, lying chiefly along the anterior bank of the central sulcus. Moreover, when compared to the movement maps, each composite muscle map for the arm coincides roughly with a major region for producing movements about a particular joint. For example, the major movement zone for the shoulder has outputs not only for affecting shoulder muscles, but also muscles acting about the elbow and the wrist. Conversely, the zone from which wrist movements are most easily evoked contains outputs which affect muscles acting about the elbow and the shoulder (7,8,11). As noted elsewhere (7), this arrangement would allow a particular movement zone to control both the primary muscles for producing that movement, and also the synergistic muscles at the same and adjacent joints that must be active simultaneously to stabilize the limb as movement occurs. Data from one monkey which illustrates this form of muscle representation are shown in figure 2.

While the functional significance of this organization is not completely clear, it can nonetheless be exploited for research purposes. For example, the rostrocaudal arrangement of each arm-muscle map along the anterior bank of the central sulcus offers a particular advantage. A multichannel electrode with recording pads at several sites along its length can be inserted parallel to the central sulcus, so that it samples neural activity at many points along one of the arm muscle maps. In this way, signals can be derived along a single penetration that encode not only particular movements, but also their underlying muscle synergies; either or both can then be exploited for control purposes. This concept is illustrated schematically in Figure 3. Currently, we are using electrodes with exactly this feature, kindly supplied to us by Dr. Kenneth Wise and his colleagues at the University of Michigan integrated circuit laboratories.

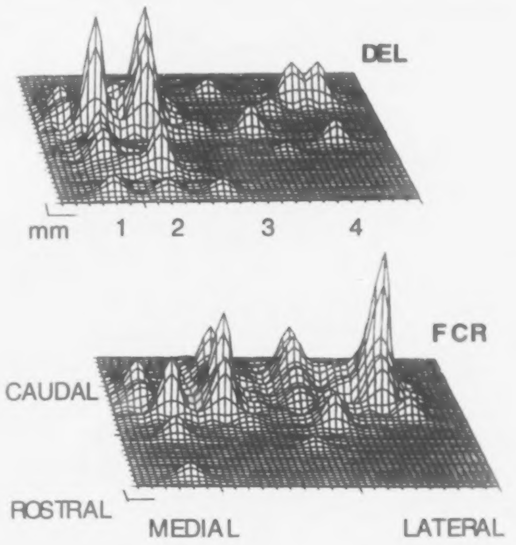


Figure 2. Comparison of maps for shoulder and wrist muscles. Each map shows reciprocal threshold values (a measure of the strength of motor output) as a function of the location of the stimulating site in Lamina V of MI. Maps are shown for a shoulder muscle (lateral deltoid or DEL) and for a wrist flexor muscle (flexor carpi radialis or FCR). Rostrocaudal and mediolateral directions are indicated. Most of the peaks in both maps lie in the anterior bank of the central sulcus. Note that the peaks for both muscles occur in four, rostrocaudally oriented bands (labeled 1-4). Peaks in the FCR map are most prominent laterally, and those in the DEL map medially, but both have representations in all four bands. For comparison, stimulation in bands 1 and 2 produced shoulder and/or elbow joint movements, those in bands 2 and 3 elbow and/or wrist movements, and those in band 4 finger/wrist movements.

Before leaving this topic, an important property of such cortical motor (and also sensory) representations must be noted. Current studies suggest that the representations are not static; i.e., they do not reflect *completely* "hardwired" or unmodifiable neural connections. Rather, while certain general features may be fixed, the details of the maps depend in part upon individual somatosensory and motor "experiences". Thus, they appear in part to be dynamically maintained, with the details of the map reflecting the synaptic "weights" or "efficacies" of afferent and intrinsic inputs to resident neurons (12,13). These "weights" are altered by sensory and motor experience, perhaps comprising part of the basis for skill acquisition. This means, of course, that the cortical "map" of the body musculature may be significantly different in an amputee or a quadriplegic patient from his or her pre-injury map; further, maps may differ significantly in detail across individuals.

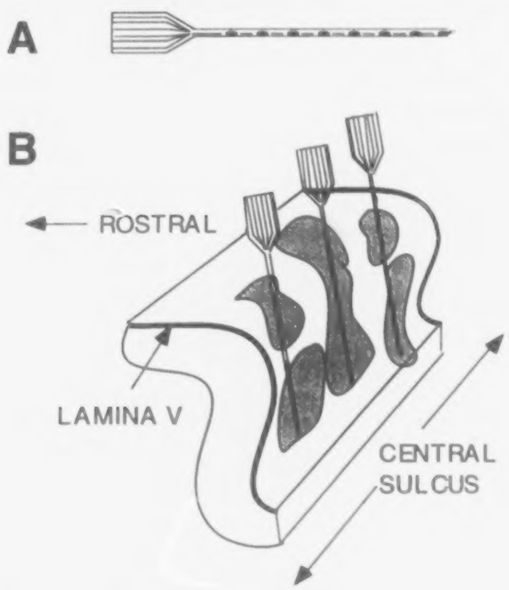


Figure 3 Matching recording electrodes to motor cortex maps. A. Design of a long electrode with multiple recording pads distributed along its shaft, for use in recording from several sites along one penetration. **B.** Insertion of these electrodes along each of the band-like arm representations (shaded regions) allows the recording of neural signals related to several muscles along the arm, as well as to movements at different joints.

Thus, ways must be found to map out cortical regions for electrode implantation in *each individual who is a candidate for a cortically controlled prosthesis.* The importance of research directed at this problem is discussed below.

Control Parameters in the Discharge of Motor Cortex Neurons

In normal voluntary movements, a number of variables are sensed and controlled by the brain. These include, but are not limited to, the following:

(1) *Joint positions*, synthesized both at rest and during movement to give limb posture and position;
(2) *End effector (hand) position* in relation to the body and to nearby objects;
(3) *Movement kinematics* (direction, velocity);
(4) *Movement force* (muscle tension and sense of effort);
(5) *Joint/limb impedance* (as signaled by levels of co-contraction of joint stabilizing muscles).

Studies with monkeys trained to make arm movements under differing requirements of displacement, velocity, and load have shown that correlates of all of these variables can be found in the movement-related discharge of MI neurons (see 7 for review). Indeed, it is the apparent encoding of so many parameters of movement in MI cell discharge that makes it such an attractive site for study of a brain controlled motor prosthesis. Some examples of the accuracy with which motor parameters can be simulated or predicted by the discharge of MI neurons may help to illustrate this point.

More than twenty years ago, Humphrey *et al.* (14,15) showed that the discharge of only 3-5 selected cortical neurons could be used to simulate - in real time - the net wrist torques generated by voluntary, isometric contractions of the wrist muscles by the trained monkey. This was viewed at the time as remarkable, for the prevailing opinion was that too little was known about neural signal processing in the cortex and spinal cord to allow such simulation. Moreover, many thousands of cortical and spinal neurons are known to be involved in producing such contractions. Yet, a surprisingly accurate simulation was accomplished with the signals of only a few selected corticospinal neurons, using rather simple mathematical procedures. The latter consisted of: (a) introduction of a time delay between neural discharge and simulated joint torque (muscle tension), equal to the sum of neural conduction, synaptic transmission, and muscle excitation times; (b) a summation of the weighted discharge frequencies of the cells, as might occur biologically if their outputs converged onto a common set of spinal neurons; and (c) low-pass filtering of this sum, with a filter whose properties simulated the mechanical or contractile time constants of the wrist muscles. An example of one of these simulations is shown in Figure 4.

As encouraging as these simulations seemed at the time, however, they were trivial in view of those that would be required to simulate natural movements of the arm and hand. Because of its multiple joints and directions of joint movement, the arm has multiple degrees of freedom. Moreover, movements about one of these joints and the stabilization of non-moving, supporting joints is produced by the intricately orchestrated activities of some 19 major muscles in the arm. Because of this complexity, researchers have sought to identify parameters in the discharge of MI cells that might relate quantitatively to some higher order variable that would more simply describe a multi-joint movement (16-18). Fortunately, such a variable has been identified: it is the direction in space of a reaching movement or, alternatively, the path followed by the hand (so-called "end-effector") during such a movement.

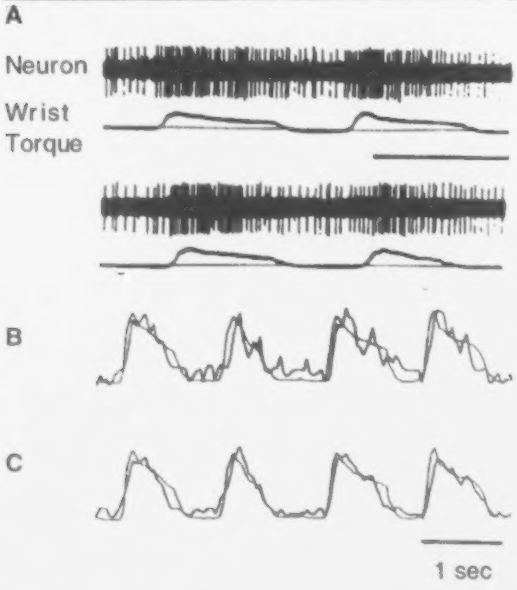


Figure 4 Simulation of motor output from cortical cell discharge. A. Discharge of a single cortico-spinal cell (upper trace) during generation of isometric wrist torques transients (lower trace), for four consecutive wrist muscle contractions. Extensor torque is upwards. **B.** Simulation of the recorded torque using the smoothed discharge frequency of the cell shown. The lighter trace shows the same torque transients shown in A, while the irregular, darker trace is the simulated torque, computed as described in the text. **C.** The match is improved when the summed discharge rates of five, simultaneously recorded cortical cells is used in the simulation. Adapted from Humphrey (15).

Georgopoulos *et al.* (16,17) were the first to discover that the discharge of some motor cortex neurons is related to the direction of reaching. As a population, the cells appear to encode and perhaps control movement direction. For example, the discharge rate of any one of these cells is maximal during reaching in a particular direction, falling off as a cosine function as the hand movement deviates from this "preferred" direction.

An important feature of the observed population of these neurons, however, is that the "preferred" directions differed for different cells. Georgopoulos *et al.* proposed, therefore, that the activity of this cell population could "encode", or be a command signal for, the direction of reaching (16,17). For example, as the focus of peak activity shifted across the population of these cells, the direction of reaching would correspondingly change. To illustrate this hypothesis, Georgopoulos *et al.* estimated how a population of the cells would behave during a particular reaching movement, using data from cells recorded sequentially during many repetitions of movements in a series of eight different directions. To do this, each cell's preferred direction was first identified by a unit vector. This vector was then weighted by the relative changes observed in the cell's premovement firing rate, as the animal reached in a particular direction. These weighted vectors were then summed across all observed cells, for each reaching direction. The resulting "population vector" was found to predict closely the actual direction of reaching for the eight directions studied. An example of these computations for one such movement is shown in Figure 5.

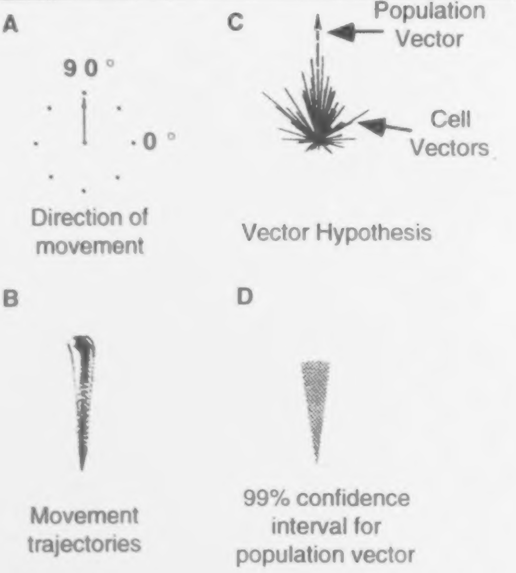


Figure 5. Predicting the direction of reaching from cell population discharge. A. The direction of the movement to be predicted: the animal extends its arm, moving its hand in a direction straight ahead of its body. **B.** Display of the trajectories of the hand recorded during several of these movements. **C.** The directions of the weighted cell discharge vectors for a sample population of MI neurons. The discharge of each cell was recorded sequentially, with electrode movements from cell to cell while the animal repeated the movement many times. The resulting population vector (sum of the weighted cell vectors) points in the direction of reaching. **D.** Confidence interval for the computed population vector. Adapted from Georgopoulos *et al.* (17). Used with permission.

The hypothesis that the discharge of some motor cortex cells might control the *direction* of reaching was strengthened further by two additional discoveries. First, the cell population discharge vector was found to predict accurately the direction of a movement some tens to hundreds of milliseconds *before the movement actually began*, giving credence to the belief that it is in fact a command signal for directional reaching (17). Second, it also predicted accurately the changes in hand path that an animal made when it was required to alter the direction of a reaching movement in progress; again, changes in the predicted direction led those of the actual movement (17). In fact, the correlation of MI cell discharge with hand path is sufficiently high that it can predict the path of a monkey's hand on a computer touch screen, as it traces out a figure by tracking a moving target cursor with its finger (19).

The implications of these studies for brain control of an arm prosthesis are profound. For example, if one could record from a number of these cells simultaneously, the "population discharge vector" could be used to estimate the desired path of a hand movement. This movement could then be produced (in real-time) by the most efficient muscle stimulation or actuator manipulations available. That is, it would not be necessary to simulate in detail the complex patterns of muscle activity that would normally be required to produce these movements.

Unfortunately, however, we do not as yet know how these "directionally tuned neurons" are distributed in the brain. For example, how many of these cells exist per unit volume in MI cortex? Do those with similar directional "tuning" occur in clusters, or are they randomly distributed throughout MI? Could a sufficient number of them be detected by electrodes placed in MI at surgery, without having to search the cortex with numerous electrode penetrations as the patient performs arm movements? All of these are questions that must be answered by future research, if the promise of these elegant neurophysiological studies for cortical control of an arm-hand prosthesis is to be realized.

Plasticity of Motor Cortex Discharge

We turn now to an important consideration. Is the discharge of motor cortex cells sufficiently "plastic", i.e., modifiable through learning, to be easily adapted by a patient for control of a "new limb"? The proximity of these cells to the final output of the motor system, and the fact that new motor skills can be learned throughout one's lifetime, suggest an obvious affirmative answer. However, there are hidden complications when one considers how these modifications are produced.

With appropriate auditory and visual feedback, for example, animals can learn to vary the discharge of cortical cells so that their activity controls directly some external device; for example, the position of a pointer on a meter, or of a cursor on a computer screen (20,21). Moreover, it has been known for decades that brain injured patients can learn new movements to accomplish tasks that were previously performed by muscles that are now paralyzed. The examples given earlier of the use of EMG signals from shoulder muscles to control an artificial hand, or the stimulation of paralyzed forearm muscles, are instances of such compensation.

These adaptations depend strongly, however, upon somatosensory feedback. When monkeys learn to manipulate devices controlled directly by the discharge of motor cortex cells, for example, they make small, often unnoticed movements of the body parts which these cells normally control (22). Moreover, those cells whose discharge is most easily modified are those that control the wrist and hand, where the density of sensory receptors in the arm is highest, and from which sensory feedback would be maximal. These observations suggest that sensory feedback from the arm and hand is important in an animal's ability to modify the discharge of MI cells and couple this discharge to movements of some external device. In agreement, lesions of somatosensory feedback pathways in the dorsal columns of the spinal cord greatly diminish an animal's capacity to modify MI cell discharge, under the training paradigms used (23). Other investigators have found that dorsal column lesions also impair voluntary movement, but for only one to two weeks, after which skilled arm-hand movements returned (24).

Additional research on the role of somatosensory feedback in the adaptability of cortical cell discharge is therefore needed. If the findings summarized above are confirmed, other neuronal populations or brain sites must be considered as sources of signals for prosthesis control. New imaging technologies hold promise for identifying sites in the human cerebral cortex whose activity may be less controlled by sensory feedback than is MI, and which would, therefore, be important candidate sites for derivation of prosthesis control signals (25,26).

DIRECTIONS FOR FUTURE RESEARCH

We conclude this brief review with consideration of two areas in which new research is needed. The first of these aims at a better understanding of how sensorimotor regions of the brain are modified by spinal cord injury. The second relates to the very difficult problem of finding brain signals that have sufficient information for extraction of useful control parameters, and which are stable for the years to decades that realization of a neural prosthesis will require.

1) Brain imaging studies of candidates for a neural prostheses

To study the feasibility of a neurally controlled motor prosthesis, we and others have focused on regions of the primate cortex that have a high degree of topography, strong movement-related cell discharge, and other useful properties. That is, we have attempted to maximize our probability of success by studying brain regions whose properties would be "ideal" for prosthesis control. It is time, however, to research the more realistic case; namely, motor regions in the brains of patients with spinal cord injury. Recent advances using functional imaging of the brain to study voluntary movement processes in normal subjects can clearly be extended to accomplish this goal (25,26).

In the patient with spinal cord injury, it is very likely that cortical motor areas have been reorganized extensively; there are some data available from magnetic stimulation of the motor cortex in such patients to illustrate this point (27). With cervical cord injuries, somatic sensory pathways are often damaged and corticospinal axons, which mediate voluntary movements, may be severed. At present, we do not know if corticospinal cells will survive this insult. Animal studies suggest that they may degenerate within one to two years after cervical axotomy (28), but the transection in humans is farther from the cell body than is the case in these studies. More cells may thus survive in humans. As a result of these changes in input and output, the synaptic organization of the cortical motor areas will change significantly. In such cases, it is not clear to what extent the MI motor cortex will still be a viable site for derivation of control signals.

We badly need, therefore, more functional imaging studies of brain activity during voluntary movement in normal patients, so that we have a database to compare with those from the neurological patient. We can then carry out similar studies with paralyzed patients who *imagine* or *try* to move body parts that are no longer under their control. In this way, we can identify the sites of cortical activity - wherever these might be - that correlate with each type of imagined movement. A study of this type will, in fact, be needed for each patient who is a candidate for a brain-controlled, motor prosthesis.

2) *Finding stable neural signals for prosthesis control*

Many investigators have assumed that signals recorded from single neurons will be the most useful for prosthesis control. There are several reasons for this assumption. First, neurons with different control functions may be intermingled in the cortex, or their distributions may overlap significantly. By isolating the discharge of single neurons, those with different functions can be separated, and control signals can be derived from the most appropriate. Second, single neuron spikes are of sufficient amplitude and have sufficient frequency (discharge rate) modulation to be suitable for real-time control. That is, averaging of activity over several trials or "attempts" to make a movement, often done to improve signal-to-noise ratios when electroencephalographic (EEG) signals are studied, is not necessary. Thus, significant delays between brain commands for movement and the occurrence of that movement - which can only impair motor performance - can be avoided. Finally, by recording from many neurons simultaneously, one may be able to extract several parameters that would be useful for prosthesis control. Recognition of these advantages has spurred attempts to develop long-term, single neuron recording methods, and techniques for on-line separation of the discharge of many simultaneously recorded neurons.

But single neurons die - at a rate of some 50,000/day in the normal adult human brain - and they are easily injured by electrodes that must be in close proximity to them to isolate their spike activity. To date, we know of only one case in which recordings have been obtained from the same, clearly identified neuron for more than three weeks (29). Thus, a way of obtaining long-term, stable signals with adequate real-time information content is at present unavailable.

We should note that some researchers have found that externally recorded EEG potentials may be useful for prosthesis control, where the actuator functions are simpler than those required for a limb prosthesis (see, for example, Wolpaw, this volume). This approach has the advantage of being non-invasive, and it is useful with current technologies. A clear disadvantage, however, is that extraction of a useful signal may require averaging over many brain events, thus precluding its use for the real-time control of movement.

We need additional research, therefore, into alternative approaches. One of these may consist of multi-unit recordings. By using electrodes with appropriate tip or pad sizes, one can record "multi-unit" potentials from small groups of active neurons. Though of smaller amplitude than single unit spikes, and containing the spikes of cells with perhaps differing motor functions, these multi-unit potentials may nonetheless correlate better with certain motor commands than with others. Moreover, by recording at many sites, one may be able improve this specificity by using spatial patterns of cell activity. Finally, multi-unit potentials may be recordable for longer periods of time than are single neuron spikes. For these reasons, we are now pursuing the multi-unit approach in our laboratory; only time will tell if it is a reasonable compromise.

664

ACKNOWLEDGEMENTS

Supported by contract N01-NS-1-2308 from the Neural Prosthesis Program.

REFERENCES

(1) Vodovnik, L.; Long II, C.; Reswick, J.B.; Lippay, A., and Starbuck, D. (1965) Myo-electric control of paralyzed muscles. *IEEE Trans. Biomed. Eng*., BME-12: 169-172.

(2) Evarts, E.V. (1966) Pyramidal tract activity associated with a conditioned hand movement in the monkey. *J. Neurophysiol*., 19: 1011-1027.

(3) Frank, K. and Hambrecht, F.T. (1977) Present status of neural prostheses: visual, auditory, and motor. *Clin. Neurosurg.*, 24: 337-346.

(4) Mauritz, K.H. and Peckham, H.P. (1987) Restoration of grasping functions in quadriplegic patients by Functional Electrical Stimulation (FES). *Int. J. Rehabil. Res.,* 10 (Suppl 5): 57-61.

(5) Stein, R.B.; Charles, D. and Walley, M. (1983) Bioelectric control of powered limbs for amputees. *Advances in Neurology*, 39: 1093-1108.

(6) Rizalotti, G.; Gentilucci, M.; *et al.* (1987) Neurons related to goal-directed motor acts in inferior area 6 of the macaque monkey. *Exp. Brain Res*., 67: 220-224.

(7) Humphrey, D.R. and Tanji, J. (1991) What features of voluntary motor control are encoded in the neuronal discharge of different cortical motor areas. In, *Motor Control: Concepts and Issues,* edited by D.R. Humphrey and H.-J. Fruend. New York: John Wiley & Sons, pp. 413-444.

(8) Humphrey, D.R. (1986) Representation of movements and muscles within the primate precentral motor cortex: historical and current perspectives. *Fed. Proc*., 45: 2687-2699.

(9) Waters, R.S.; Samulack, D.D.; Dykes, R.W and McKinley, P.A. (1990) Topographic organization of baboon primary motor cortex: face, hand, forelimb, and shoulder representation. *Somatosen. Mot. Res*., 7: 485-514.

(10) Donoghue, J.P.; Leibovic; and Sanes, J.N. (1992) Organization of the forelimb area in squirrel monkey primary motor cortex: representation of individual digit, wrist, and elbow muscles. *Exp. Brain Res.*, 89: 1-19.

(11) Kwan, H.C.; MacKay, W.A.; Murphy, J.T.; and Wong, Y.C. (1978) Spatial organization of primate precentral cortex in awake primates. II. Motor outputs. *J. Neurophysiol.*, 41: 1120-1131.

(12) Merzenich, M.M.; Recanzone, G.; *et al.*. (1988) Cortical representational plasticity. In *Neurobiology of Neocortex*, edited by P. Rakic and W. Singer. New York: John Wiley & Sons, pp. 41-67.

(13) Donoghue, J.P. and Sanes, J.N. (1994) Motor areas of the cerebral cortex. *J. Clin. Neurophysiol.*, 11(4): 382-396.

(14) Humphrey, D.R.; Schmidt, E.M.; and Thompson, W.D. (1970) Predicting measures of motor performance from multiple cortical spike trains. *Science*, 179: 758-762.

(15) Humphrey, D.R. (1972) Relating motor cortex spike trains to measures of motor performance. *Brain Res.*, 40:7-18.

(16) Georgopoulos, A.P.; Kalaska, J.F.; Caminiti, R.; and Massey, J.T. (1982) On the relations between the direction of two-dimensional arm movements and cell discharge in primate motor cortex. *J. Neurosci.*, 2: 1527-1537.

(17) Georgopoulos, A.P.; Kalaska, J.F.; Caminiti, R.; and Massey, J.T. (1984) The representation of movement direction in the motor cortex: single cell and population studies. In *Dynamic Aspects of Neocortical Function*, edited by G.M. Edelman, W.M. Cowan, and W.E. Gall. New York: John Wiley & Sons, pp. 501-524.

(18) Soechting, J.F. and Lacquaniti, F. (1981) Invariant characteristics of a pointing movement in man. *J. Neurosci.*, 1: 710-720.

(19) Schwartz, A.B. (1993) Motor cortical activity during drawing movements: population representation during sinusoid tracing. *J. Neurophysiol*., 70: 28-36.

(20) Fetz, E.E. and Finocchio, D.V. (1972) Operant conditioning of isolated activity in specific muscles and precentral cells. *Brain Res*., 40: 19-24.

(21) Schmidt, E.M. ; McIntosh, J.D.; and Durelli, L. (1978) Fine control of operantly conditioned firing patterns of cortical neurons. *Exp. Neurol.*, 61: 349-369.

(22) Wyler, A.R. and Burchiel, K.J. (1978) Factors influencing accuracy of operant control of pyramidal tract neurons in monkey. *Brain Res*., 152: 418-421.

(23) Wyler, A.R.; Burchiel, K.J.; and Robbins, C.A. (1979) Operant control of precentral neurons in monkeys: evidence against open loop control. *Brain Res.*, 171: 29-39.

(24) Asanuma, H. and Arissian, K. (1982) Motor deficits following interruption of sensory inputs to the motor cortex of the monkey. *EEG Clin. Neurophysiol.*, Suppl. 36: 415-21.

(25) Stephan, K.M.; Fink, G.R.; Passingham, R.E. *et al.* (1995) Functional anatomy of the mental representation of upper extremity movements in healthy subjects. J. Neurophysiol., 73: 373-386.

(26) Kawashima, R.; Roland, P.R.; and O'Sullivan, B.T. (1994) Fields in human motor areas involved in preparation for reaching, actual reaching, and visuomotor learning: a positron emission tomography study. J. Neurosci., 14: 3462-3474.

(27) Cohen, L.G.; Bandinelli, S; Topka, H.R. *et al.* (1991) Topographic maps of human motor cortex in normal and pathological conditions: mirror movements, amputations, and spinal cord injuries. *EEG & Clin. Neurophys.*, Supplement. 43: 36-50.

(28) McBride, R.L.; Harper, W.B.; and Feringa, E.R. (1990) Axotomized corticospinal neurons cannot be

retrogradely labeled with fluoro-gold one year after spinal cord transection. *Soc. Neurosci. Abstr.*, 16: 984.
(29) Schmidt, E.M.; Bak, M.J.; and McIntosh, J.S. (1976) Long-term chronic recording from cortical neurons. *Exp. Neurol.*, 52: 496-506.

Donald R. Humphrey, Ph.D.
Professor of Physiology and Neurology
Emory University School of Medicine
Atlanta, GA 30322
phone: (404) 727-0346
fax: (404) 727-2648
e-mail: drh@physio.emory.edu

CHRONIC, MULTIPLE-UNIT RECORDING OF NEURAL ACTIVITY WITH MICROMACHINED SILICON MICROELECTRODES

William J. Heetderks, M.D., Ph.D.
Neural Prosthesis Program, National Institute of
Neurological Disorders and Stroke, NIH, Bethesda, MD

Edward M. Schmidt, Ph.D.
Laboratory of Neural Control, National Institute of
Neurological Disorders and Stroke, NIH, Bethesda, MD

Abstract: During normal movements, activity of neurons in the motor cortex and other areas of the brain precedes the contraction of muscles and movement of the body. In a variety of neurological disabilities, the information flow from the motor cortex to the muscles is interrupted and no movement is possible. In these situations, it may be possible to create direct connections with neurons in motor areas of the brain and to use the information encoded by the activity of these cells to provide a direct interface for outgoing information transmission. In this paper, we review efforts to chronically record single unit neural activity in the cortex. Particular emphasis is placed on the use of micromachined, silicon microelectrode probes for chronic recording.

Background: Action potentials have been recorded in the extracellular space using microelectrodes for 6 decades. In fact, the neurophysiological studies done with microelectrodes provide much of the foundation for our understanding of motor control by the nervous system. But, despite their great success in helping elucidate the organization of the nervous system, microelectrodes have significant limitations. They provide, at best, a relatively brief glimpse of the behavior of a neuron. Recordings are typically obtained for periods measured in hours or, in some cases, days. Also, a microelectrode provides a view of the activity of only one or a few neurons at a time.

It has been hypothesized for many years (1) that neural control signals could be derived directly from the activity of neurons in areas in the motor control pathway. A direct approach to obtaining control signals would consist of observing the activity of many neurons in the motor control pathway and deriving control signals from this observed neural activity. While this direct approach has appeal because of its conceptual simplicity, implementing the technology to provide the observations is difficult. It requires that one be able to observe the activity of a number of neurons in a selected area of the brain over prolonged periods of time. The microelectrodes that provided the insight to motivate this approach are not adequate to implement it. Over the past several years, the Neural Prosthesis Program at the National Institute of Neurological Disorders and Stroke, National Institutes of Health has supported research to develop methods to chronically observe populations of cells in the brain and to demonstrate the feasibility of extracting control signals from the observed activity.

Problem Statement: In this session we focus on two questions: Can the neural activity of single neurons be observed over prolonged periods of time; and, assuming it is possible to observe activity in single neurons, can the technique used for observing single neurons be generalized to observe many neurons over prolonged periods? We then provide a summary of recent experiments at the Laboratory of Neural Control, NINDS, NIH that utilize micromachined silicon microelectrodes for chronic recording.

Chronic observation of the action potentials from a single cell: The microelectrode records activity for time periods measured in hours. Then typically the neuron is lost. An investigator then moves the microelectrode to a new location and records from another unit. Recording of the activity of a neuron over periods of years, as is desired for a cortical control device will require different techniques. In fact, there is no convincing evidence that anyone has been able to record the activity of a single, identified neuron for a period of even one year. Nevertheless, progress is being made on this problem.

To minimize the movement of a microelectrode with respect to the brain for chronic recording, Salcman and Bak (2) developed the floating microelectrode. This electrode consists of an insulated iridium needle, 75 microns in diameter and deinsulated at the tip for recording, a flexible, insulated connecting wire that connects to the back of the needle, and an epoxy ball at the junction of the needle and the flexible wire. The microelectrode needle penetrates into brain tissue and the recording tip comes into close contact with neurons and is able to record neural activity. The epoxy ball rests on the surface of the pia. This electrode conceptually "floats" on the brain and the highly flexible connecting conductor, an insulated, 25 micron diameter gold wire, produces minimal tethering as it exits through the dura.

These microelectrodes have been implanted in monkeys (Macaca Mulatta) for up to three years (3,4). The record for recording from the same identified cell (based on receptive field and firing pattern during a defined task) was 108 days. More typically, an identified cell was kept for periods of days or weeks. Some of the microelectrodes recorded neural activity during the full course of the 3 year experiment.

The microwire has also be used for chronic recording. This consists of an insulated microwire cut at the tip to expose a recording site. Dr. Humphrey will describe their use in larger animals in his presentation. Investigators report recording for periods of up to 2 years using microwires in small mammals. Chronic recording from the same cell using microwires is beginning to be studied. There is some evidence for recording from single identified cells over a period of months but more typically, the recorded cells change with time as has been the case with the Salcman-Bak electrode (5). It is unclear whether the apparent movement between the microwire recording site and neurons represents movement of the neurons or movement of the microwire.

Chronic recording has also been achieved in rats and primates using the cone electrode (6). This electrode consists of a small open-ended glass cone with recording sites located within the cone microenvironment. Prior to implantation, trophic factors are placed within the cone to promote neural and glial tissue growth into this protected area. After a recovery period, neural recordings are obtained from the electrodes placed within the cone. Recordings have been obtained for periods of up to 15 months in monkeys. Signal strength was inadequate to reliably identify single units but one can hypothesize that the neurites within the cone might not change with time.

The sieve electrode is a structure that has been used in the peripheral nervous system to record neural activity (7). An electrode structure with multiple penetrating holes is placed in-line with a severed nerve. Axons regenerate through the holes and recording sites, placed around the holes, selectively record from these axons. A similar structure might be tried in the CNS with the hope that processes in the neuropil would grow through holes placed in the shank of a microelectrode.

Another approach to making connections with specific neurons in the nervous system is the cultured neuron probe (8). This structure, which is still under development, involves growing dissociated neurons in enclosed silicon wells located within the shank of a micromachined microelectrode. The cell body of a neuron becomes mechanically trapped in the well as it grows and an electrode placed at the bottom of the well can record from this neuron. Conceptually, such an electrode structure with the growing cells will be implanted into the nervous system. Cell processes will grow out of the well and into the nervous tissue to make connections with specific CNS cells.

Recording from many cells: Wise and colleagues at the University of Michigan (9) are developing multiple site microelectrode probes for single unit recording using micromachining techniques in silicon. A variety of probes with different shank lengths and electrode site spacings can be fabricated together on one silicon wafer. The arrangement of microelectrode recording sites on an individual probe is designed by the investigator to match the specific recording target sites needed. A typical probe consists of multiple penetrating shanks arranged in a comb pattern. Each shank contains several microelectrode recording sites along its length. Conductive paths lead from each recording site to the back of the probe where connections are made to the outside world. The shanks are about 15 microns thick, about 60 microns in width and can have a variable shank length up to several millimeters.

The back section on some of the probes includes electronic circuitry to amplify recorded signals and multiplex them onto a single output line. Potentially, the signal processing circuitry to extract control signals from the observed activity could also be integrated into the probe.

Normann and colleagues (10) are developing a 3-dimensional probe for chronic recording that has the appearance of a 'bed of nails'. The probe is a 10 by 10 array of silicon needles with a single recording site placed at the tip of each needle. Each conductive shank is electrically insulated from its neighbors. The needles, which are 80 microns in diameter, are imbedded in a glass base. They are insulated along the shank except at the tip using a polymer insulation. Connections to the outside are made by connecting microwires to the individual needle heads at the back of the probe structure. This structure is also compatible with making connections at the back of the probe to an integrated circuit chip to permit amplification and multiplexing of signals.

Experience with the Michigan probes:

Methods: Probes of the Michigan design with a single shank designated the 'Schmidt' electrode were implanted in the supplementary motor cortex of the monkey (Macaca mullata). Six arrays were implanted. Each array has six sites along the shank. The sites are spaced on 200 micron centers and each site is 10 by 30 microns. The shank is 15 microns thick, 60 microns in width, and 2 millimeters in length. The back of the probe is covered with a small ball of epoxy about 1 millimeter in diameter. A six conductor silicon ribbon cable that is integral with the probe connects the probe to a percutaneous connector. Unity gain buffer amplifiers plug directly into the percutaneous connector mounted on the animals head. Signals are subsequently amplified by 20,000, band-pass filtered between 300 and 5000 Hz, recorded on tape, displayed on the oscilloscope, and processed on-line using a BrainWave® data system. Recordings were obtained when the animal executed a variety of trained motor tasks that required tracking of target(s) on an video display screen by flexion and extension of the wrist(s). The task related discharge characteristics of cells was used to identify units on a day to day basis.

Recording results: Two days after implantation, multi-unit activity was recorded at most of the recording sites. Spike amplitudes ranged from just above the noise level to 200 microvolts peak to peak in amplitude. Over the next 3 months, there was a general trend of decreasing signal amplitude with time. This was not consistent, however, and significant variation was seen on a day to day basis. It was not unusual to see no activity on an electrode site on one day but to see several units and large spikes from one or two units on the following day. In one case, early in the experiment, we saw evidence of activity from specific neurons migrating from one site along the shank to another over a period of a few days suggesting movement of the electrode but this was not typical.

This general trend of decreasing spike amplitude continued and after about 5 months the largest recordable spikes were just above the level of the noise. At that time we began to investigate the effect of applying a small bias voltage to the electrodes through current limiting resistors. Following passage of as little as 10 nanoamperes of current for periods of 4 seconds, we found that the electrode impedance dropped significantly. This drop in impedance was accompanied by a return of the ability to record action potentials with good signal to noise ratios. Spikes of over 400 microvolts in peak to peak amplitude were recorded. Typically several units were recorded at an active site. The activity on adjacent sites of a probe (200 microns away) was consistently from a different set of neurons. On average, the electrode site closest to the tip of a probe displayed the greatest signal to noise ratio but there were numerous exceptions.

A few of the units displayed highly characteristic task related behavior. These units could be followed over weeks on the basis this behavior. One unit identified both behaviorally and on the basis of its characteristic waveshape was followed for a period of 5 weeks after the electrodes had been in place for 9 months. During the 10th month, this electrode failed due to loss of the iridium at the recording site.

Discussion: There are several approaches being taken to chronic recording that might be suitable for a cortical control device. The work by Wise and Normann represent two generalizations of the probe devised by Salcman and Bak with the enhancements of providing many sites on one needle and providing many needles in an array. The microwires are also closely related to this electrode design. The cone electrode represents another approach to chronic electrode design that includes an area on the electrode structure for neural processes ingrowth.

Broadly, all these microelectrodes can be classified as non-integrating (microwires, floating microelectrodes, and silicon microprobes) and integrating (cone electrodes, sieve electrodes, cultured neuron probes). The term integrating here refers to the extent to which the electrode becomes incorporated into the tissue of the brain. Functionally, an integrated electrode, when moved a few hundred microns would be expected to move with the nearby neural tissue and recorded activity would not change. When moved too far, the connection with tissue would be disrupted and no recordings would be obtained. A non-integrating electrode when moved a few hundred microns would record from a new population of cells.

Non-integrating electrodes have been in use for some time. The record for long term recording (3 years) from a chronically implanted probe and the record for recording from the same unit (108 days) were obtained with non-integrating probes. The observations to date, however, suggest that these probes will not provide stable recordings in the brain over periods measured in years. Normann has suggested that the multishank array may be more stable than individual shanks and this needs to be studied.

The movement problems of non-integrating electrodes are likely to be worse when recording in larger brains because of the increased movement of the brain relative to the cranium with angular acceleration. Similarly, we hypothesize there will be significant differences in the ability to record chronically from identified units related to the physical activity of an animal with a sedentary animal providing increased stability. These factors suggest that comparisons of different electrodes may be animal dependent.

Integrating electrodes may be better suited to chronic recording over periods of years. The studies of Kennedy are encouraging in this regard. However, it remains to be demonstrated that these electrodes can record chronically from identified cells. Generalization of the cone electrode to many sites may be difficult. The cones are much larger than silicon microprobe shanks and it seems likely that implanting many cones would cause significant damage to the target area of the brain.

The silicon microprobes represent a site count generalization of the floating microelectrode. Early concerns that it would be impossible to record at locations other than the tip of a microelectrode have proved to be false. Sites separated by 200 microns on the shank record from different populations of cells. In acute studies, with microprobes connected to a microdrive, identified neurons can be recorded as electrodes are moved over distances of about 30 microns suggesting that electrodes designed to record from separate populations might be more closely spaced than 200 microns. Histological results indicate less reaction along the shank of an electrode than at its tip suggesting recording sites along the shank are to be preferred.

The microelectrode arrays will be important for demonstrating chronic recording in a single electrode. Arrays with closely spaced recording sites could provide source localization of spike action potentials providing additional evidence for identifying single units. Multiple sets of source localizing recording arrays could provide information on the question of whether the electrode is moving in the brain tissue or the neurons are moving relative to the electrode and brain tissue.

There remain problems that must be solved before we can chronically record from a single cell in the CNS over periods of years. A major problem continues to be providing a stable relationship between the recording site and the surrounding neurons within the region of about 30 microns around the recording site.

The cortical layers of the brain consist of neurons surrounded by glial cells except at the synapses. An extracellular fluid rich in hyaluronic acid bathes the glia and neurons. Glia grow and attach to some surfaces better than others and the mechanisms of this adhesion are becoming understood. In, particular, laminin and firbronectin are two glycoproteins that promote adhesion and spreading of glia (11). Providing the electrodes with a surface of one of these materials (or partial functional analog such as the RGD tripeptide) may provide a mechanism whereby the electrode shank is integrated into the tissue of the brain providing prolonged stability. David Martin at the University of Michigan and Jay Hickman at SAIC are presently looking into ways of modifying the surface of electrodes in this way.

Another approach that may permit stabilization of an electrode would involve fabricating an electrode with multiple holes along its shank The goal would be to encourage glial ingrowth through the electrode shank providing increased integration of the electrode into the CNS tissue.

Summary: An electrode capable of recording from a neuron in the CNS over periods of years has not been achieved. However, significant insight into the design of this electrode is being obtained. The approaches being pursued by different investigators are complimentary and it seems probable that a successful chronic electrode will use features from several of the current designs. When a technique for recording from one neuron has been developed, the techniques of micromachining offer promise that it will be readily generalizable to many neurons. In the meantime, the multielectrode arrays will be essential in demonstrating the ability to record from a single electrode site.

Acknowledgements: Electrodes were supplied by the Solid State Electronics Laboratory at the University of Michigan. Special thanks to Jamie Hetke who was responsible for bonding, potting, and delivering the electrodes. Thanks to Nabil Azzam and Donna Cole at NINDS for assistance in preparation of the histological slides and animal training.

References:

1. F.T. Hambrecht and K. Frank: "Future possibilities for neural control" in Advances in Electronics and Electron Physics 38 L. Marton ed., Academic Press, New York, 1975.
2. M. Salcman and M.J. Bak: "A new chronic recording intracortical recording electrode", Med. Biol Eng. 14: 42-50, 1976.
3. E.M. Schmidt, J.S. McIntosh and M.J. Bak: "Long term implants of Parylene-C ccoated microelectrodes", Med. & Biol. Eng. & Comput. 26:96-101, 1988.
4. E.M. Schmidt, M.J. Bak and.J.S. McIntosh: "Long-term Chronic Recording from Cortical Neurons", Expt. Neurol. 52:496-506, 1976.
5. D.J. Woodward, personal communication, 1995
6. P.R. Kennedy, S.S. Mirra, and R.A. Bakey: "The Cone Electrode: Ultrastructural studies following long-term recording in rat and monkey cortex" Neurosci. Lett. 142:89-94, 1992.
7. T. Akin, K. Najafi, R. Smoke, and R.M. Bradley: "A micromachined silicon sieve electrode for nerve regeneration applications", IEEE Trans on BME 41:305-313, 1994.
8. J. Pine: Quarterly progress reports, NIH contract N01 NS 3-2393, #1-6, 1993-1995.
9. J. Ji and K.D.Wise: " An implantable CMOS circuit interface for multiplexed microelectrode recording arrays", IEEE J. Solid-State Circuits, 27:433-443, 1992.
10. C.T. Nordhausen, P.J. Rousche, and R.A. Normann: "Optimizing recording capabilities of the Utah intracortical electrode array", Brain Res. 637:27-36, 1994.
11. A. Bignami and D. Dhal: Glial Cells in the Central Nervous System and Their Reaction to Injury, RG Landes Company, Austin, Texas 1995.

COMMAND-CONTROL SIGNALS FROM THE NEURAL ACTIVITY OF MOTOR CORTICAL CELLS: JOY-STICK CONTROL

William J. Heetderks, M.D., Ph.D.
Neural Prosthesis Program, National Institute of
Neurological Disorders and Stroke, NIH, Bethesda, MD

Andrew B. Schwartz, Ph.D.
Barrow Neurological Institute,
Phoenix, AZ

Abstract: During normal movements, activity of neurons in the motor cortex precedes the contraction of muscle and movement of the body. In a variety of neurological disabilities, the information flow from the motor cortex to the muscles is interrupted and no movement is possible. In these situations, it may be possible to create direct connections with the cells in the motor cortex and to use the information encoded by the activity of these cells to provide a direct interface for outgoing information transmission. In this presentation we demonstrate that control signals for an 8-direction joy-stick can be derived from the neural activity of a population of as few as 10 cells in the motor cortex. Accurate control signals can be realized as quickly as 200 ms. after presentation of a stimulus suggesting the possibility of super human performance in some tasks.

Background: A variety of neurological conditions leave an individual unable to send information and commands from brain to muscle. In spinal cord injury, brain-controlled command sources are needed to control functional neuromuscular stimulation systems. In the locked-in syndrome, a brain-controlled command source is needed to permit even the simplest communication. The concept of extracting command and control signals directly from the neural activity in the brain has existed for a long time (1) but the practicality of such an approach has been in question. Before the neural activity of groups of individual neurons can be used for command-control, two core questions must be addressed: How can neural activity be observed in a chronic, reliable fashion and, if the activity is observed, how can the observed activity be processed to provide command-control signals.

Research Questions: In this presentation we address the second question as two sub questions. First, if the activity of many neurons in the motor cortex can be observed, can it be used to generate command signals for a simple command device like a joy-stick? Second, to generate reliable command signals, how many neurons will be required and how will the variability of neural response affect the number of units required?

Methods: Task related neural activity was recorded from the motor cortex in the right and left hemispheres in three animals. Details of the experimental methods are described in (2). Briefly, monkeys were trained to move their hand from a central rest position to one of 8 radially spaced "out" positions in response to a light cue that indicated which direction to move the hand. Using extracellular metal microelectrodes, neural activity was recorded during this task. For a total of 150 individual neurons, five trials were conducted for each of the 8 "out" positions in three animals. For each trial, the movement of the hand, the times of occurrence of spikes, and the time of acquisition of the "out" target was recorded.

Model: Many neurons in the motor cortex cooperate to define and control the skillful movements in normal individuals. In the performance of a specific trained motor task, the neurons response, within a set time interval, can be described by :

$$r = f(x_1, \ldots x_q) + n, \qquad (1$$

where r is the response of a neuron to a particular trial, f is a general function of the parameters x_1 to x_q that characterize the motor task and n is a noise term.

In the performance of the pointing task described in this report the only controlled task variable is the direction of movement Ø. It has been shown (3) that the response of neurons in the motor cortex to this task can be approximated as :

$$r = b_1 + b_2 \operatorname{Cos}(\varnothing - \varnothing_p) + n, \qquad (2$$

where r is the discharge rate of the neuron, $Ø$ is the direction of the movement, and b_1, b_2, n, and $Ø_p$ are constants for a particular neuron. 'n' is a noise term that reflects the trial to trial variation in the response. 'b_1' is the average discharge rate of the neuron, 'b_2' is the modulation depth with changes in movement direction and '$Ø_p$' is the preferred direction(direction of maximum response).

Trigonometric identity substitution in equation 2 gives:

$$r = b_1 + c \text{ Cos } (Ø) + d \text{ Sin } (Ø) + n \quad (3$$

$$\text{where } c = b_2 \text{ Sin } (Ø_p)$$
$$\text{and} \quad d = -b_2 \text{ Cos } (Ø_p).$$

Equation 3 clearly depicts the vector nature of the neural response in this task with the x and y components being linearly separated.

We also define a simplified neural response as:

$$s = 1 \text{ if } r >= b_1 \qquad (4$$
$$s = 0 \text{ if } r < b_1.$$

This 2-state description of the neural response treats the neuron as a binary element that is on or off depending on whether its spike rate is above or below its mean rate of firing.

Estimation Problem: For a given "out" direction, a neural population response vector is constructed from a subset of m of the 150 neurons as:

$$\underline{R} = [r_1, \quad ,r_m], \qquad (5$$

where the first term of the vector is the response of the first neuron, the second term is the response of the second neuron etc. By pooling the single unit responses into vector responses a total of 40 neural response vectors can be constructed from the data , five for each of the eight "out" target directions. We ask the question: Given a task related neural population response vector $\underline{R}$, estimate the direction of movement that will occur. If we can successfully predict the direction of the movement then this predicted movement direction can be used as a control signal. In this presentation we will use the population vector described by Georgopoulos (3) to estimate the direction. This approach estimates the direction of movement as being the vector sum of the responses of the individual neurons with the magnitude of each neural contribution being equal to the magnitude of the neural response r_i for trial i and the direction of each response being given by the preferred direction of the neuron $Ø_p$.

Results: Estimation of the "out" target direction using a population of 150 neurons results in clustering of the responses across trials for the different 'out' targets. When the trial responses are plotted on a 2 dimensional scatter plot (corresponding to the x and y components of the movement direction), 8 clusters are readily seen corresponding to the 8 "out" targets. Thus, when the motor cortical cells being observed are committed to performing this task, it is possible to derive a command-control signal with 8 states corresponding to the 8 "out" target directions. When the number of neurons in the pool that defines the population response is reduced, the separation between the clusters for the different "out" targets becomes less and the clusters are no longer distinct. With population vectors that include only a small number of neurons, there is overlap in the clusters.

A measure of the separation of the clusters, the average distance (in units of within cluster standard deviation) between cluster centers was computed. As the number of neurons in the population is increased from 10 to 150, the average cluster separation increased from 3 to 14. Complete separation of the clusters for different "out" targets was obvious in the scatter plots when the average separation was greater than about five. This required about 50 neurons when the neurons were drawn at random from the population of 150 cells. If neurons were selected for their performance on this task (high ratio of b_2/n), as few as ten neurons provide an average separation of over eight and thus provide good estimates of target direction.

With the output of each neuron defined in a binary fashion using equation 4, binary neural population vectors $\underline{S}$ similar to equation 5 were constructed. Estimating the "out" target direction using these vectors also resulted in the "out" targets clustering into eight distinct populations. Using a select population of 50 neurons with high (b_2/n), the average cluster separation was decreased from 11.5 to 9 when neural response was treated as a binary function. This separation permits accurate estimation of target direction.

Discussion: The results are consistent with the conclusion that an 8 direction command signal can be generated from the activity of between 10 and 50 neurons in the motor cortex. The number of cells required depends on the task related information content of the activity of the cells. Fewer cells are required if they have a large ratio of (b_2/n). Considering a cells neural activity as a binary function produced a small but significant decrease in the separation of clusters but still permitted accurate estimates of "out" target movement direction.

These results are based on neurons recorded over several months time and recorded in multiple animals. The results were obtained in neurologically intact animals. Thus they are consistent with the feasibility of a cortical control channel but do not demonstrate its feasibility for specific applications. Demonstration of a command-control signal would require the simultaneous recording of activity in one animal. Nevertheless, the assumption that this population activity is representative in a statistical sense of what would be recorded simultaneously in a single individual seems reasonable. In fact, the cross correlations that can be observed in simultaneously recorded data might be expected to provide additional information about the direction of movement.

References:

1. F.T. Hambrecht and K. Frank: "Future possibilities for neural control" in Advances in Electronics and Electron Physics 38 L. Marton ed., Academic Press, New York, 1975.
2. A.B. Schwartz: "Motor cortical activity during drawing movements: Single -unit activity during sinusoidal tracing", J. Neurophysiol. 68:528-541, 1992.
3. A. P. Georgopoulos, R. E. Kettner, and A. B. Schwartz: "Primate motor cortex and free arm movements to visual targets in three-dimensional space II. Coding the direction of movement by a neuronal population", J. Neurosci. 8: 2928-2937, 1988.

The Utah Intracortical Electrode Array as a Possible Motor Cortex Interface

Edwin M. Maynard, Craig T. Nordhausen, Richard A. Normann
University of Utah
Slat Lake City, UT 84112 USA

Abstract

The potential of the Utah Intracortical Electrode Array (UIEA) as a direct interface to motor cortex is investigated. The dependence of the spatial and temporal characteristics of a typical multi-unit response to thresholding are investigated. It is shown that adjustment of the detection threshold voltage alters both the specificity and variability of the multi-unit response. An attempt to explain these features is developed through a model which relates the radius of the recording sphere to a particular threshold voltage. These results are combined in the evaluation of the performance of a simple eye tracking task using neural information recorded from visual cortex. The results show that recordings of multi-unit neural activity can be used to provide robust control of an external device.

Background

Recent advances in the design and manufacture of silicon-based electrode arrays have permitted various cortical structures to be targeted for potential neuroprosthetic applications. One particular prosthetic application of interest is the design of systems that will enhance a quadraplegic patient's ability to interact with his environment [1]. Such assistance systems as they exist today are controlled by remaining articulating muscles or voice recognition systems. Various limitations inherent to these control schemes have led to research efforts aimed at using recorded neural activities of motor cortex as command signals. Direct neural interfaces with motor cortex may overcome the most significant deficiencies of current technologies: limited number of command channels, inability to decode volition proportionally, susceptibilty to environmental noise and interference.

While it is not possible to dictate all of the recording characteristics of such a direct interface, a number of desirable features can be suggested. For a direct cortical interface to have a large number of command channels, the particular recording technique used needs to be able to isolate the activity of small regions of cortex evoked by the conscious desire to perform particular motor tasks. A high temporal resolution is desired to be able to isolate subtle changes which may encode proportionality or other features of motor tasks. In addition, such an interface should perform robust neural detection tasks without the benefit of external stimulus phase locking and in near real time. Because of the spatially disperse nature of the neural activity in motor cortex which results in movement, the recording technique should permit the placement of large numbers of recording devices in the targeted motor representation.

Any direct interface with motor cortex will rely on the recording of extracellular action potentials. These potentials can be recorded either as field potentials, high signal-to-noise ratio (SNR) single unit spike trains, or multi-unit spike trains. In general, all three methods require the use of signal averaging techniques to either improve the SNR of the actual neural signal or reduce the variability inherent to the responses of single neurons. The effect of spatial averaging in EEGs is to "blur" the location and extent of the recorded activity. This increases the effective recording volume of the electrode and lowers the number of command channels that can be effectively used. The temporal averaging used in both EEGs and single-unit microelectrode recordings to increase signal-to-noise ratios typically requires an external synchronization and slows the detection process. This begs the question of whether there exists a technique by which one can record from a large number of cortical sites and maintain desirable recording characteristics.

Research Questions

To evaluate the application of the UIEA as a potential motor cortex interface there were a number of questions which must be addressed. The first question concerned the effect of the UIEA's large recording surface area on the types of responses recorded. To approximate the number of neurons recorded from we attempted to estimate the size of the recording volume using a model based on work by Rall [2], standard electromagnetic principles [3], and well-known histological data [4]. These results suggest that it is possible to "tune" the size of the recorded neuronal population by adjusting the detection threshold level. Finally, to investigate whether this feature of multi-unit responses was useful, we designed and implemented a tracking task which would use as input the responses from the array.

Methods

The UIEA was implanted in the visual cortex of cats maintained on Halothane(0.7%-1%) anesthesia. Paralysis was maintained with periodic injections of pancuronium bromide(.2mg/ml). Depth of anesthesia was monitored through heart rate, end tidal CO_2, and temperature. After refraction, the cats were presented with a computer-controlled moving bar stimulus (light on dark field) of superthreshold intensity. The velocity, orientation, and size of the bar of light could be adjusted. The responses were band-passed filtered (100-3kHz) amplified typically 50000x, digitally acquired (20kHz sample rate) and stored for later off-line analysis.

Results

Figure 1 shows a typical response recorded by an electrode of the Utah Intracortical Electrode Array. These responses are characterized by the presence of a number of neurons firing with the presentation of a bar stimulus (black bar). The amplitudes of these action potentials can range from the noise band (6 μV) to a maximum around 150 μV. A sub-population of these action potentials typically can be extracted through the thresholding process.

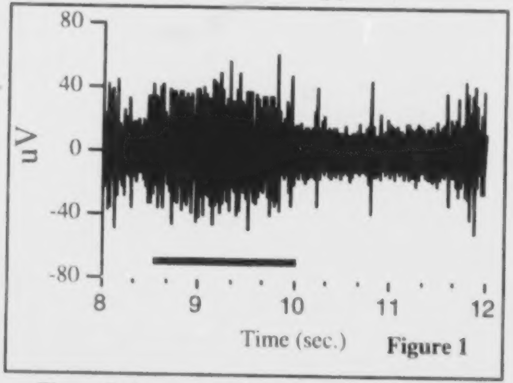


Figure 1

Figure 2 shows the effect of thresholding on the receptive field size of a multi-unit response. One can easily see that as the threshold is decreased, the receptive field size (represented by the columns) increases and the coefficient of variability (represented by the line) decreases. The VEP represents the response of a very large number of neurons to a bar stimulus and has the largest receptive field size and lowest coefficient of variance. At the highest threshold value (~43 μV), this is the response of essentially a single unit; it has the smallest receptive field and the highest coefficient of variance.

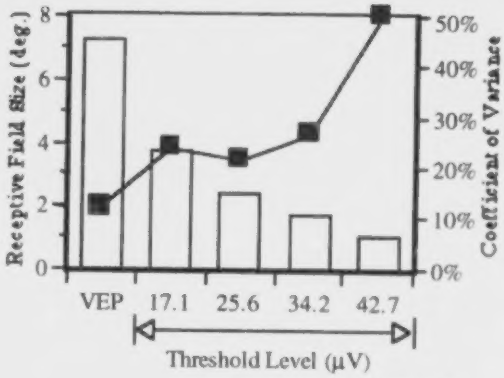


Figure 2

In an attempt to quantify the size of the recorded neuronal population, a model was adopted using Rall's work, accepted values for cortical resistivity, and standard electromagnetic techniques. Table 1 was generated from results in Drake et al (1988) and compares the recording radius to the possible number of neurons present in the recording sphere for a variety of threshold values. On comparison with the response depicted in Figure 1, there can be seen an obvious discrepancy between the predicted number of neurons to be recorded from and the probable number present in the recording.

Table 1

Threshold Voltage	Recording Radius (μm)	Number of Neurons
20 μV	111	310
30 μV	102	236
40 μV	94	187
100 μV	69	74
500 μV	34	9

Figure 3 shows the performance of a system designed to predict the position of a receptive field from the neural response elicited by a moving light bar stimulus. The broken line indicated the position of the receptive field as it was deflected through 30 degrees of visual angle. The solid line shows the error between the position of the receptive field and the calculated position based on the evoked response.

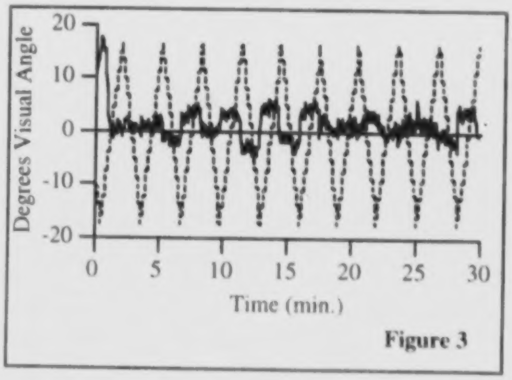


Figure 3

The mean magnitude of the error was 2.4 degrees. The results shown in Figure 2 suggest that "tuning" the response through adjustment of the threshold voltage could improve the performance of this system. This experiment has yet to be performed.

Discussion

The selection of visual cortex over motor cortex for this preliminary research was based on a number of experimental considerations. The use of a sensory cortex has the advantages of easily correlating evoked responses to a known stimulus in an anesthetized animal. In addition, we were able to avoid the need to behaviorally train the animals to perform stereotyped motor tasks. Primary differences between the two cortices are the lamina thickness, origin of inputs, and cellular density. Although there are important anatomical and physiological distinctions between the visual and motor corticies, we believe that there are enough similarities to validate the use of visual cortex as a model for motor cortex. However, we look forward to extending this research into motor cortex.

The number of neurons enclosed in a "recording sphere" assosciated with a particular recording threshold predicted by our model differed from what we observed using our electrode array. There are a number of possible explanations for this significant discrepancy. Our composite model is based on a number of assumptions that have yet to be tested in visual cortex. Particular areas of the model which may be oversimplified are the modeling of the extracellular resistance as homogeneous and the absence of neuroanl orientations on the amplitude of the extracellular potentials. Other factors which might account for the "missing" neuronal population could be neuronal damage [5] by the impact insertion process [6], the effects and level of anesthetic used, or that a bar stimulus is too specific to evoke large population responses. A further area of consideration is the effect of shunting by the large surface area of our electrode on the amplitude of the recorded signals.

All of these factors could contribute to a reduction in the observed neuronal population. Although the analysis of our responses is complicated by the high degree of action potential superposition, this alone cannot account for such a large discrepancy. Because of this discrepancy, it is impossible to correlate our threshold voltages accurately to a particular recording radius. Nevertheless, the results of the model can be seen as an upper limit on the recording radius for a given threshold level. These values would suggest that the 400 μm spacing of our electrodes constrain them to record from independent populations of neurons.

This still leaves the question as to why the tracking task performs as well as it does with multi-unit responses. It is our feeling that these multi-unit responses reflect an integration of the various features of the stimulus. Adjustment of the voltage threshold has the effect of selecting the amount of integration performed by the neuronal population. Lowering the threshold has the effect of decreasing response variability by increasing the amount of stimulus integration. Practically this means that any type of stimulus can evoke a response and noise is mistakenly interpreted as a response. Raising the threshold results in the response being more specific to the stimulus but response variability increases due to a decrease in integration. Multi-unit activity thresholded at a moderate value integrates the signal to decrease the response variability yet maintains enough stimulus selectivity to accurate "tag" the evoked response.

The UIEA has the capability of recording from a large number of spatially fixed areas in the motor cortex. We have shown that by adjusting the threshold applied to the multi-unit response, the size of the population of neurons recorded from can be adjusted to affect the specificity and variability of the response. Unlike EEG-based implementations, the spatial specificity and high temporal resolution of these responses provide more robust signals with which to extract command signals. This will permit the end-user the highest degree of flexibility in the control of external devices.

References

[1] Schmidt, E.M.. Ann. Bio. Eng. 8:339-49. 1981.

[2] Rall, W. Biophysics J. **2**:145-67. 1962.

[3] Drake, K.L., Wise, K.D., et al. IEEE Trans. Biomed. Eng. 35(9): 719-32. 1988.

[4] Freygang, W.H. and Landau, W.M. J. Cell. Comp. Physiol. **45**: 377-392. 1955.

[5] Schmidt, S., Horch, K., Normann, R.A. J. Biomat. **27**:1393-9. 1993.

[6] Rousche, P.K. and Normann, R.A. Ann. Biomed. Eng. **20**: 413-22. 1992.

This work was supported by NSF Grant BCS9110767

Edwin M. Maynard
506 Biopolymers Research Building
University of Utah
Salt Lake City, UT 84102 USA
(801) 581-3817

IDENTIFICATION OF CORTICAL SIGNAL PATTERNS RELATED TO HUMAN TONGUE PROTRUSION

Jane E. Huggins,[1,2,3] Simon P. Levine,[1,2,3] Ramesh Kushwaha,[4] Spencer BeMent,[5] Lori A. Schuh,[4] Donald A. Ross[6]
Bioengineering Program,[1] Rehabilitation Engineering Program,[2] Physical Medicine and Rehabilitation,[3] Neurology,[4] Electrical Engineering and Computer Science,[5] Neurosurgery,[6] University of Michigan

ABSTRACT

Specific signal patterns related to voluntary tongue protrusion have been identified in cortical electrical signals from human subjects. While a subject repeats a tongue protrusion activity cortical electrical signals are recorded from electrodes on the cortex. Triggered averaging is used to create templates of cortical activity time-locked to the tongue protrusion. Templates are accepted as valid signal patterns related to tongue protrusion based on comparison to a control template from the same electrode. These signal patterns can then be used to develop detection methods for a direct brain interface.

BACKGROUND

Most assistive technology interfaces require some physical movement. A direct brain interface would bypass inoperative nerves and muscles and instead use input and commands directly from the brain. An initial application of the interface would be to provide an opportunity for communication to locked-in patients. Later versions of the interface could be used as an alternative or additional control for a variety of assistive technologies such as powered mobility and functional electrical stimulation.

The concept of a direct brain interface to control assistive technology has been under investigation for the past two decades. Animal research has demonstrated the feasibility of detecting cortical movement-related waveforms with accuracies of 83% (8) and 90% (1). Research with surface-recorded EEG waveforms in humans have demonstrated detection accuracies of 50-95% (5, 6) and have been used to operate interfaces providing information transfer of 0.2 bits/second (2). An interface using intracranial electrodes and a heavily structured input environment provided an ALS patient with a communication rate of 10-12 words/minute (7). Additional information on the characteristics of the signal patterns related to specific voluntary activities is also available (3, 4). The work of these researchers is strong evidence that an interface utilizing cortical activity is feasible.

PURPOSE

This paper reports on methods of recording and identifying specific signal patterns related to voluntary activities. These methods are used to identify specific signal patterns related to tongue protrusion. Obtaining data containing signal patterns and validating their relation to voluntary activities forms the first step in the development of a direct brain interface. Once signal patterns related to specific voluntary activities are identified, real-time detection methods can be developed and tested using the recorded data. A method can then be selected based on relative performance to form the foundation of a direct brain interface.

METHOD

Subjects Four subjects have been studied to date in this on-going project. The subjects are patients in an epilepsy surgery program who have had electrodes placed on their cortex for diagnostic purposes prior to surgery. Electrodes are usually placed over temporal or frontal lobes near sensory-motor cortex and language areas, but occasionally over other areas as well. As part of the presurgical evaluation, signals from these electrodes are continuously recorded. During data collection sessions, recordings of these signals are made in parallel.

Voluntary Activities The suite of activities for a subject to perform is determined in consultation with a physician familiar with the patient in order to choose activities which should require activation of parts of the brain near the electrode positions. In order to use triggered averaging for analysis of the data collected, the activities must also produce a recordable action. Tongue protrusion fits these requirements for most potential subjects and is one of a limited number of activities for which signal pattern information has been published (4). Other activities used include flexing a finger, hand, or arm, smiling, sipping or blowing on a straw and verbal activities such as reading a word and naming a picture. This paper reports only on analysis of data for tongue protrusion. (Analysis of data for other voluntary activities will be presented separately.)

Equipment The electrodes used for recording are platinum electrodes arranged 1 cm apart in strips of 4 to 6 electrodes or in arrays of 20 to 64 electrodes. During data collection, a bifurcated cable is used to allow the electrocortical signals to be sent in parallel to the standard electroencephalography recording system used for clinical monitoring and the Cadwell Spectrum 32.(a) The Spectrum is capable of recording up to 32 channels of data at 200 Hz with a low frequency cutoff as low as 0.02 Hz and a high frequency cutoff up to 100 Hz. The actual number of electrocortical channels available for each patient is determined by clinical monitoring requirements. The trigger signal for tongue protrusion is a square wave produced by a calibrator upon activation of a mechanical switch. After the signals have been recorded, they are transferred to a Macintosh IIfx(b) for analysis using custom LabVIEW(c) programs.

Recording The first step in a data collection session is the integration of the Spectrum into the current recording setup by inserting a bifurcated cable into the standard cabling. Frequency and sensitivity settings are then adjusted to eliminate saturation. Next, the subject is instructed in the activity to be performed and trigger equipment for the activity is set up. The experimenter prompts the subject to perform the activity by raising a hand or card. Prompts are delivered at intervals of 3 to 10 seconds. A typical data collection session involves approximately 50 repetitions each of four activities. (Experimental circumstances do not always permit exactly 50 repetitions.)

Analysis Triggered averaging is used to produce templates which are analyzed to identify if signal patterns related to the voluntary activity are recorded. The trigger signal (square wave) is detected using a simple threshold. Templates start two seconds prior to the trigger signal and are three seconds in duration. Thus, a template can include signal patterns from mental preparation for the activity and sensory feedback.

Identification of a signal pattern related to a specific activity is based on comparison of two segments of the template. The control segment is the interval before the prompt, 1.0 to 2.0 seconds prior to the trigger. The signal segment is the interval from -1.0 to +1.0 seconds. The difference in the means ($\Delta\mu$) of the rectified data from these segments is expressed in standard deviations of the control segments. A conservative criterion of two standard deviations has been chosen for identification of valid signal patterns related to the voluntary activity. The p-value based on the Student t-test is then calculated to determine the statistical significance of $\Delta\mu$.

RESULTS

Based on the two standard deviation criterion, templates from three of the four subjects were determined to contain cortical activity related to tongue protrusion. For the remaining subject, three templates had a $\Delta\mu$ value exceeding one standard deviation, but none met the two standard deviation criterion. The number of recording sites that yielded templates meeting the two standard deviation criterion for each subject were: 0/24 (DT), 1/31 (JP), 7/31 (DV), and 9/20 (JR). The maximum $\Delta\mu$ was 8.23 standard deviations. Samples of templates which meet the two standard deviation discrimination criterion are presented in Figure 1 along with a representative template from the fourth subject. Figure 2 shows two of the averaged templates from Figure 1 together with the first five unprocessed data segments used in its calculation. Figure 3 shows the placement of the electrodes for the templates shown in Figure 1. For three of the subjects, electrode grids were positioned primarily over the temporal lobe, with two of the grids extending over the sensory-motor cortex as well. The third grid extended over the inferior temporal lobe. For the fourth subject, electrode strips were placed over lateral and inferior temporal lobe.

These templates illustrate the variations in the shape of the signal patterns. For each subject, the shape of signal patterns recorded by electrodes in close proximity tended to be similar. Similarities in the shape of the signal pattern were also apparent between subjects, although not necessarily from similar locations. Based on visual comparison, the templates appear similar to published data about signal patterns related to tongue protrusion (4).

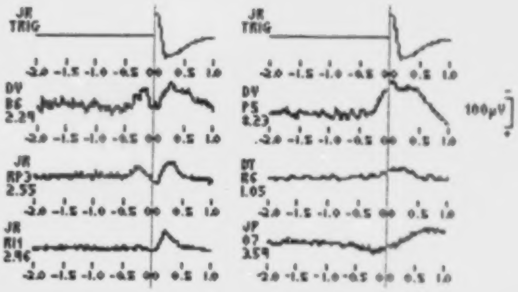


Figure 1: Averaged templates of a trigger and signals for tongue protrusion in four subjects. Each template has a subject indicator, an electrode designation, and the $\Delta\mu$ between the control template (-2.0 to -1.0 sec) and the signal template (-1.0 to +1.0 sec); $p<0.001$ for all templates. Data segments used for averaging were 31(DT), 42(DV), 52 (JR), and 53 (JP).

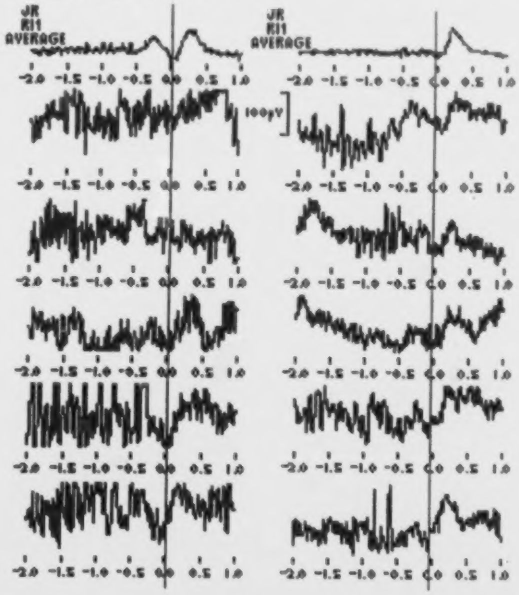


Figure 2: The averaged templates and unprocessed data for the first five trigger points.

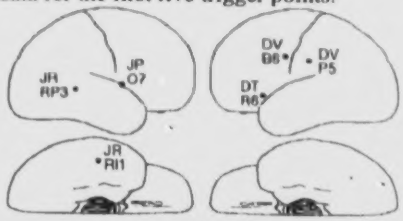


Figure 3: Electrode placement for Figure 1 templates.

DISCUSSION

The analysis of the data from these four subjects has demonstrated the ability to record and identify signal patterns related to tongue protrusion. The signal patterns seen are considered to represent cortical activity related to tongue protrusion instead of volume conduction from the muscular movement for several reasons. First, the difference in position of the grid electrodes is small relative to the distance from the electrodes to the tongue muscle. Any artifact from this muscle should therefore be consistent across the entire grid. Secondly, these electrodes record from an extremely local area. Pulse artifact is the only artifact typically seen by the epilepsy surgery program. Finally, some of the signals begin about a half second prior to the trigger, before the initiation of muscle movement.

Not surprisingly, signal patterns related to tongue protrusion were identified from electrodes over cortical areas normally considered to be tongue representation cortex (DV-B6, DV-P5). Some electrodes positioned a short distance from the traditional tongue representation cortex also recorded signal patterns related to tongue protrusion (DT-R6, JR-RP3, JP-O7). However, signal patterns corresponding to tongue protrusion were also unexpectedly recorded from the inferior surface of the temporal lobe. These areas are not known to be involved in tongue protrusion, nor are they in close proximity to pre or supplementary motor areas. Further study may provide more information on the origin of these signals.

The temporal location of the signal patterns relative to the trigger is important for two reasons. First, the portion of a template designated as the signal segment affects the value of $\Delta\mu$. For subject DT, recalculating the $\Delta\mu$ value for the three best templates with a signal segment of -0.5 to +0.5 (as opposed to -1.0 to 1.0) will raise $\Delta\mu$ above the two standard deviation criterion. Future plans include methods to more specifically identify a time interval for the signal component. Secondly, the identification of signal patterns with components prior to the trigger point is important to the development of a direct brain interface for people with severe disabilities unable to control the related muscles.

The selection of voluntary activities for a particular subject is a difficult part of this on-going study. Since the geography of the brain varies across subjects, standard structure/function information will be augmented with individual motor and language mapping information whenever possible. The range of possible voluntary activities for operation of a direct brain interface is quite broad. Besides simple movements and verbal activities described, purely mental activities like mental arithmetic, event recollection, or object visualization could also be considered. Signal pattern identification for these activities is more difficult, however, since no externally recordable trigger is available.

When a trigger signal resulting from an activity is not available, it may be possible to calculate signal templates by triggering on the prompt. However, the time duration between prompt and activity may not be consistent enough for triggered averaging. Another possibility would be to use a template from a different subject performing the same activity. The similar templates produced by patients DV and JR indicate that this possibility is worthy of further investigation. A brain computer interface could be implemented, however, before a definitive solution to this problem is determined. Patients with progressive disabilities, such as ALS, could establish templates prior to loss of function which could be used for interface operation as the disability progressed.

Conclusion The signal pattern templates related to tongue protrusion provide a strong basis for comparing different methods of detecting cortical electrical activity related to voluntary activity. The data collection and signal pattern identification process represents the first step in the development of a direct brain interface for people with severe physical disabilities. Once appropriate methods are developed, real-time testing for assistive technology control will be performed with human subjects.

REFERENCES

(1) M.D. Craggs, Cortical Control of Motor Prostheses: Using the Cord-transected Baboon as the Primate Model for Human Paraplegia. **Adv Neurol**, 10:91-101, 1975.

(2) L.A. Farwell, E. Donchin, Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. **Electroenceph clin Neurophysiol**, 70:510-523, 1988.

(3) A. Ikeda, H.O. Luders, R.C. Burgess, H. Shibasaki, Movement-related potentials recorded from supplementary motor area and primary motor area. **Brain**, 115:1017-1043, 1992.

(4) A. Ikeda, H. Shibasaki, Invasive Recording of Movement-Related Cortical Potentials in Humans. **J Clin Neurophysiol**, 9(4):509-520, 1992.

(5) Z.A. Keirn, J.I. Aunon, A New Mode of Communication Between Man and His Surroundings. **IEEE Trans Biomed Eng**, 37(12)1209-1214, December 1990.

(6) D.J. McFarland, G.W. Neat, R.F. Read, J.R. Wolpaw, An EEG-based method for graded cursor control. **Psychobiology,** 21(1):77-81, 1993.

(7) E.E. Sutter, The Brain Response Interface: Communication Through Visually-Induced Electrical Brain Responses. **J Microcomputer Appli**, 15:31-45, 1992.

(8) C.D. Woody, and M.J. Nahvi, Application of Optimum Linear Filter Theory to the Detection of Cortical Signals Preceding Facial Movements in Cat. **Exp. Brain Res.**, 16:455-465, 1973.

MANUFACTU0RERS

(a) Cadwell Laboratories, Inc, Kennewick, WA 99336
(b) Apple Computer, Inc, Cupertino, CA 95014-6299
(c) National Instruments, Austin, TX 78730-5039

ADDRESS

Jane Huggins, M.S.
Rehabilitation Engineering Program
1C335 University of Michigan Hospital
Ann Arbor, MI 48109-0032

PROCESSING OF SINGLE-TRIAL, MOVEMENT-RELATED ERP'S for HUMAN-MACHINE INTERFACE APPLICATIONS

Steven G. Mason[1] **and Gary E. Birch**[1,2]

[1] Department of Electrical Engineering
The University of British Columbia
Vancouver, B.C. Canada

[2] The Neil Squire Foundation
Vancouver, B.C. Canada

ABSTRACT

We have been researching methods to automatically recognize single-trial, voluntary movement-related potentials (VMRPs) from one- and two-dimensional human electroencephalograph (EEG) signals. Our ultimate goal is to develop a method that is usable as a real-time human-machine interface. This is a difficult asynchronous signal detection problem because the transient, time-varying VMRP signals reside in non-stationary background EEG activity with signal-to-noise ratios typically below –5dB. Although previous research has identified the temporal characteristics of ensemble-averaged VMRP signals, little is known about the space-time characteristics of single-trial VMRP signals. This paper presents our efforts to automatically recognize single-trial VMRPs from single and multiple electrodes.

BACKGROUND

Most often the greatest failing of assistive devices for severely disabled persons is the inadequacy of the human-machine interface (HMI). With a universal effective and efficient interface, current technology has the capability of providing substantial independence and hence, a greatly improved quality of life for even the most severely disabled persons. In pursuit of an ideal universal human-machine interface, researchers have been studying the feasibility of utilizing electrical brain potentials to directly communicate to peripheral devices. One of the most significant obstacles that must be overcome in pursuing this ideal interface is the establishment of a signal processing method that can extract event-related potentials (ERPs) from single EEG observations (i.e., single-trial EEG).

A few researchers (for example, [1][2][3]) have previously attempted EEG-based interfaces built on classifying EEG frequency signatures or controlled by visual-evoked potentials (VEPs). As a method of communication, these techniques tend not to be efficient human-machine interfaces because the user cannot pay attention to his environment or he cannot control the timing of an action.

Our research focuses on EEG patterns related to voluntary movement because the user can control the timing of an action and is free to focus on his operating environment. The recognition of a Voluntary Movement-Related Potential (VMRP) for a HMI is an asynchronous signal detection problem. This contrasts with most EEG research which has focused on signal extraction and classification of time-locked signals. The problem is complicated by the fact that the signal-to-noise ratio (SNR) of a VMRP is typically less than -5dB.

The rest of this paper describes the processing methods we have developed to extract and recognize single-trial VMRPs and the results of our evaluations.

SINGLE-ELECTRODE PROCESSING METHODS

The Outlier Processing Method (OPM), describe in detail in [4], uses robust statistical processing methods and a time-varying autoregressive (AR) model of spontaneous EEG to estimate the spontaneous (background) EEG from the one-dimensional observed EEG signal. This estimate effectively filters out transient signals, such as a VMRP, that do not fit the AR model in the OPM. The single-trial VMRP is then calculated as the difference between the observed EEG and estimated spontaneous EEG sequences. The heart of the OPM algorithm is a robust signal estimator that is used to generate the EEG estimate from the observed process. This estimator treats the VMRP as a collection of (correlated) additive outliers and it uses robust statistics and time-invariant influence functions to remove these outliers from the observed sequence. This approach has the advantage that the technique does not depend on a model of the VMRP. Methods that depend on a model of the VMRP are disadvantaged because the accuracy of the single-trial VMRP estimate is easily biased by inaccuracies in the VMRP model. Additionally, the implementations of these VMRP-dependent methods are restricted to detection and extraction of a particular VMRP, e.g., an index finger VMRP, so multiple implementations are required if more than one VMRP is to be detected.

An investigation into the viability of the OPM was carried out on single-trial EEG data from four subjects. The EEG was collected under two conditions: an active task in which the subject performed a skilled thumb movement and an idle task in which the subject remained alert but did not carry out any motor activity. The results of this investigation demonstrated that consistent single-trial, movement-related information can be successfully extracted using the OPM. Using decision criteria set to minimize false positives, over 80% of the active trials (over the four subjects) were classified correctly and only 1.7% of the idle trials were incorrectly classified as active (false positives) [4][5].

Although these results were encouraging, the OPM technique could rarely generate an optimal VMRP estimate. This is because OPM's signal estimator could not be set to be both a) sensitive enough to detect and remove the VMRP, and b) insensitive enough so that it does not erroneously remove parts of the spontaneous EEG sequence. Thus the performance of the OPM is compromised due to opposing conditions.

It was subsequently demonstrated [6] that by introducing time-varying influence functions into OPM's signal estimator the algorithm could generate a significantly better VMRP estimate. However, the performance of the modified OPM, as illustrated by experiments with simulated and real EEG, was sensitive to the estimate of the location of the VMRP, which was assumed to be unknown. We are currently researching methods to accurately estimate the location (detect the presence) of the asynchronous VMRP from the non-stationary, coloured-noise background EEG activity.

MULTIPLE-ELECTRODE PROCESSING METHODS

The OPM algorithm has only been implemented on single electrodes and hence it does not make use of the information in the spatial domain. Since the signals are spatially distributed across the scalp, one would suspect that incorporating spatiotemporal characteristics into the EEG noise model will improve the algorithm's classification performance.

This work follows our desire to develop a spatiotemporal noise model that will improve the classification performance of the OPM algorithm and make the algorithm more robust against transient noise and other event-related potentials (ERPs).

The work to date has been a systematic exploration of spatiotemporal characteristics of single-trial VMRPs [7]. The goal of this work has been to find signal features that can be used for direct classification or as a VMRP locator. A combination of empirical experimentation and the study of cognitive motor processing theory has led us to investigate the time-frequency characteristics of various electrode pairs and the spatial relationship between these characteristics. Our initial investigations, using the Exponential Distribution time-frequency kernel [8], have demonstrated that by using a set of time-frequency characteristics we could differentiate single active trials from idle trials with close to 100% accuracy for single electrode pairs. When utilizing spatial information, that is combining signals from multiple electrode pairs, we could differentiate active trials from idle trials with 100% accuracy. We are currently seeking to confirm these findings across a larger subject pool. By combining these results, which provide location information, with the modified OPM described above, we would potentially have a very effective single-trial processing method.

SUMMARY

Our efforts towards the development of an VMRP-based human-machine interface have demonstrated some promising results. However, this field is still in its infancy and several challenging research problems in both single- and multiple-electrode signal processing still need to be solved.

REFERENCES

[1] Z. Keirn and J. Aunon, "Man-machine communications through brain-wave processing," *IEEE Engineering in Medicine and Biology*, vol. 9, no. 1, pp. 55–57, 1990.

[2] E. Dewan, "Communication by voluntary control of the electroencephalogram.," in *Proceeding of the Symposium on Biomedical Engineering*, vol. 1, pp. 349–351, 1966.

[3] J. Vidal, "Real-time detection of brain events in EEG," *Proc. IEEE*, vol. 65, no. 5, pp. 633–641, 1977.

[4] G. Birch, P. Lawrence, and R. Hare, "Single trial processing of event related potentials using outlier information," *IEEE Trans. Biomed. Eng.*, vol. 40, no. 1, pp. 59–73, 1993.

[5] G. Birch, P. Lawrence, and R. Hare, "Extraction of motor related activity from single trial EEG," in *Proceedings of the IEEE Engineering in Medicine and Biology Society, 10th Annual International Conference*, (New Orleans, Louisiana: U.S.A.), Nov. 4–7, 1988.

[6] S. Mason, G. Birch, and M. Ito, "Improved single-trial signal extraction of low SNR events," *IEEE Trans. Signal Processing*, vol. 42, no. 2, pp. 423–426, 1994.

[7] S. Mason, G. Birch, S. Tajwar, and M. Palmer, "The space-time characteristics of brain potentials related to single voluntary movements," in *Proceedings of the IEEE Sixth SSAP Workshop on Statistical Signal and Array Processing*, (Victoria, B.C., Canada), October, 1992.

[8] H. Choi and W. Williams, "Improved time-frequency representation of multicomponent signals using exponential kernels," *IEEE Trans. ASSP*, vol. 37, no. 6, pp. 862–871, 1989.

ACKNOWLEDGMENTS

Funding for the research described in this paper was provided by NSERC (grant number OGP0090278) and the B.C. Health Research Foundation.

Steven Mason
Department of Electrical Engineering
University of British Columbia
2356 West Mall
Vancouver, B.C. Canada V6T 1Z4
(604) 822-3611

ELECTROCORTICAL DIFFERENCES ACROSS COMPUTATIONAL PARADIGMS

Gary J. Ramah, M.S.
Biometrics Research - Highland Drive VA Medical Center
Armstrong Laboratory, San Antonio TX - U.S. Air Force

ABSTRACT:

Current direct brain interface research methods require training tasks that can represent changes along some cognitive dimension. Such tasks are appropriate for the development of a "thought based" communication channel for people with severe motor disabilities. A pair of tasks that have identical sensory and motor components and differ only along a computational dimension is described. An ERP component reflecting differences between these tasks is reported from the pilot data acquired on three subjects.

INTRODUCTION:

In order to provide a communication channel for people with severe motor disabilities and without gaze control it is necessary to be able to differentiate between at least two cognitive states. This ability requires the identification, isolation and classification of those EEG components that differ from one state to the other.

Previous paradigms have relied on the capturing of spatio-temporal EEG patterns that originate from the subject's preparing for voluntary finger movement. (Pfurtscheller et al., 1991) Once captured and classified, this signal can then be used to differentiate between the user's desire to move a computer cursor either left or right. During the system's classification training phase, the subject sees different visual stimuli (target on left or right) and responds with different motor activity (left or right index finger). As training continues the actual finger movement is eliminated and the cursor is eventually controlled "by thought alone".

It has been shown that minute muscular contractions are produced in response to visualization of movement even without conscious perception of such movement. (Jacobson, 1930). Even though the subjects are not aware of the movement they are still activating portions of the motor cortex that might not be functioning in patients with severe motor disabilities.

Since locked-in patients do not have the ability to control any movement, such a training paradigm will ultimately fail to transfer to this patient population. Therefore, a new paradigm is proposed which uses the same visual and motor components and differs only along a cognitive dimension. This new paradigm has the user perform simple arithmetic computations in response to visual cues. The computation performed can then be used to identify the user's specific command.

METHOD:

There were three subjects: 2 male (ages 40 and 44) and one female (age 30). Each subject was seated in front of a blank computer screen where the task instructions were subsequently presented. In both tasks a pair of single digit numbers were presented to the subject. In one of the tasks the subject was instructed to respond to the greater of the pair by pressing the corresponding number (1-9) on a keypad using the right hand. In the second task the subject was instructed to respond with the absolute difference between the pair again using the same keypad. Subjects were instructed to determine this absolute difference by first identifying the greater of the pair and then subtracting the smaller number from it.

There were a total of 100 trials of each task type and the order of the tasks was randomized by subject. The subject's reaction time and the actual keypad response were recorded for each trial.

EEG RECORDING:

A standard 10/20 electrode placement was employed providing 21 channels of EEG referenced to linked ears. It had a lower cutoff frequency of .53 Hz and an upper cutoff frequency of 70 Hz with a sampling rate of 125 Hz. The EEG was stored on an optical disk continuously throughout the experiment. Stimulus onset and subject's responses were time marked within the EEG data file.

DATA PROCESSING:

Event-related potentials (ERPs) where computed from the spontaneous EEG using the stimulus onset as the time locking event. The 2 seconds immediately following the stimulus onset was marked as a possible candidate for averaging. Only those trials where the subject responded accurately were retained for further processing. Once trials with eye movement artifacts were rejected, the resulting data were averaged together to form a single ERP record for each of the two separate conditions. These ERP records where then compared for systematic differences between the two tasks.

RESULTS:

All three subjects displayed a similar ERP component that appears to index the computational difference between the two tasks. The task requiring the subject to identify the greater of the two numbers elicits a greater negativity, on the order of 3-5 uVs, than does the absolute value task as can be seen in Fig. 1. The two task ERPs are superimposed and show detectable differences only within this time period.

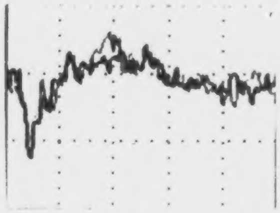


Fig.1

This negativity arises in the frontal and central anterior regions at approximately 850-900 ms after stimulus onset and lasts approximately 75-125 ms.

DISCUSSION:

This experiment has shown that it is possible to detect small differences between simple computational tasks using time locked ERPs. It is much more likely that these types of tasks will transfer to a patient population with severe motor disabilities since these tasks only differ in the mental computation being performed and not the motor responses themselves.

Future research interests include: EEG classification of these tasks from single trial experiments and developing other visualization tasks that can be used for computer control through EEG.

REFERENCES:

Jacobson, E., 1930, Imagination of Movement Involving Skeletal Muscle, American Journal of Physiology, 91, 567-608.

Pfurtscheller, G., Flotzinger, D., Mohl, W., 1991, BRAIN-COMPUTER INTERFACE: Prediction of Hand Movements from Single Trail Multi-Channel EEG Data with a Neural Network-Preliminary Results, #299, Institutes for Information Processing Graz, Austria

ACKNOWLEDGMENTS:

I would like to thank Dr. Stuart R. Steinhauer and Dr. Ruth Condray for their help throughout this experiment.
I would also like to acknowledge the support of the Department of Veterans Affairs in supplying laboratory facilities and with the Armstrong Laboratory in the equipment for this experiment.

Mail Correspondence to:

Gary J. Ramah, M.S.
Biometrics Research, 151R
VA Medical Center
7180 Highland Drive
Pittsburgh, PA 15206

Toward a P300-based Computer Interface

James B. Polikoff, H. Timothy Bunnell, & Winslow J. Borkowski Jr.
Applied Science and Engineering Laboratories
Alfred I. Dupont Institute

Abstract

This paper describes our initial research into the use of the P300 event related potential as a control signal in a computer interface for locked-in patients. These experiments are directed toward development of a device which uses the occurrence of a P300 to control motion of a cursor on a computer screen. Simultaneous target-detection tasks are presented in four compass positions (N, E, S, W) on a computer screen. The subject is instructed to detect targets in one of the positions corresponding to the intended direction of cursor movement. EEG signals from scalp electrodes at Fz, Cz and Pz are collected and averaged for targets in each of the four locations and the direction of movement is indicated by the highest P300 peak amplitude. Variables such as target on-time, ISI, null-target inclusion, and trial averaging are manipulated and the results are discussed in terms of a rate vs. accuracy trade-off.

Introduction

There exists a significant population who, due to disease or injury, are totally paralysed but have normal or near-normal brain function. In such cases, called Locked-in-Syndrome, the individual is aware of his or her surroundings, but has no way of communicating with the outside world. In cases where the person has even a slight degree of voluntary movement (e.g., eyebrow motion), it is possible to use that movement as a switch for controlling a computer. Likewise, when the person has good eye control, he or she can be fitted with an eye-tracking device to control cursor movement on a computer screen. In many cases, however, the individual may have no reliable voluntary motion to attach a switch to, and eye-movement may not be precise enough to use with an eye-tracking device. In such cases, the only possible method of communication would be to use electrical signals produced by the brain as a switching device for computer interaction. In order to achieve this, a reliable, detectable brain-signal must be found. Wolpaw, et al. (1991) was able to train subjects to voluntarily adjust the amplitude of scalp-recorded mu rhythm. The mu rhythm amplitude was assessed and translated into up and down cursor movement. Although a fair amount of training is required, this method has the advantage of using signals that are endogenous to the subject. At present, however, only one-dimensional cursor movement can be achieved.

Because of its robustness, we believe that an evoked electrical potential, called P300, may serve as a good candidate for an EEG-based computer interface. The P300 is a late positive wave that occurs between 250 and 800 milliseconds after the onset of a meaningful stimulus. It was first reported in 1965 as a late positive component occurring in response to task-relevant stimuli (Sutton et al., 1965; Walter, 1965). Sutton et al concluded that the late positive component was related to the subject's psychological reaction to the stimuli and not the physical characteristics of the stimulus. In fact, two years later, Sutton et al (1967) discovered that a P300 could be elicited by the omission of a stimulus if its omission was task-relevant. Attempts have been made to use P300 as a control device. Farwell and Donchin (1988) used P300s to operate a computer-based communication device by presenting letters and commands in a matrix and repeatedly flashing each row and column. P300s were elicited when the row or column of the element that the subject was focusing on was flashed.

In the present experiment, we will explore the possibility of using P300s to control cursor movement on a computer screen by presenting simultaneous visual target-detection tasks (oddball paradigms) and measuring peak P300 amplitudes to targets occurring at each of four compass locations (N, E, S, W). Peak amplitudes are expected to be greatest for P300s in response to the direction that the subject is attending to.

Method

Subjects were seated in a sound attenuated chamber facing a monochrome monitor 18 inches from the subject's face. The central fixation point was a cross. There were four target arms (compass positions N, E, S, W) with a target (a cross) at the end of each arm and one centimeter away from the central fixation point. Each stimulus was presented for 250 msec with an interstimulus interval of either 750 or 1,000 msec. There were two different stimulus sets: in the first, each of the four target crosses was replaced by an asterisk one at a time and in random order; in the second, a null-stimulus was included, in which no asterisk appeared. The subject was instructed to fixate the central point and count the number of times one particular cross (N, E, S, or W) was replaced by an asterisk. The order of asterisk substitution was random without replacement within each set of four (asterisk always appearing) or five (null included) stimuli. The target stimulus occurred with a probability of 0.25 in the first case, and 0.2 in the second. When a blink was detected (any signal beyond a preset threshold on the EOG channel), that stimulus trial was discarded, and was presented again later in the set. No set was complete until at least one good (non-blink) trial was recorded for each target position. Thus, each set consisted of at least four or five trials (more if the subject blinked). Sessions consisted of 50 complete sets. For the pilot data to be presented here, two subjects recorded data for the case where the target probability was 0.2, and three subjects recorded data for target probability 0.25 conditions.

Data Acquisition. Grass silver-silver chloride electrodes were placed according to the international 10-20 system at Fz, Cz, and Pz and referenced to bilateral (joined) earlobe electrodes. The EOG was recorded from an electrode as SO2 (inferior and lateral to the right eye) also referenced to bilateral earlobes. The three EEG channels and single EOG channel were amplified 50,000 times (Med Associates AG-100 physiological amplifiers), bandpass filtered between 0.15 Hz and 150 Hz, and digitized (12-bit resolution) at a 300 Hz sampling rate on an IBM compatible 486 computer with an 8-channel DSP card. Data recording for each trial began 50 msec before presentation of the target stimulus and continued for a total of 650 msec. Thus, 600 msec of EEG data were recorded for each channel following target onset. These data were saved for subsequent analysis.

Data Analysis. While the data to be presented here are based on off-line analysis of collected data, we are modeling a real time process in which the computer estimates the direction in which the subject wishes to move the cursor, moves the cursor one step in the estimated direction, obtains another estimate of the desired direction, and so forth. It is in the nature of the task that each estimate must be independent of the last estimate since the subject must be free to change cursor direction at will. The estimated direction is based on comparing P300 levels for targets on each arm of the cursor and selecting the largest P300 level as the most likely direction for cursor motion. This comparison can be made as soon as a single set (i.e., four target positions) has been obtained, or EEG activity for each target location can be summed over a series of sets to obtain a more stable P300 estimate. One issue we address in our analyses of the data is the trade-off between fast, but more error-prone, and slow, but more accurate cursor motion.

Another speed-accuracy trade-off often cited in P300 studies relates to the frequency with which a target is presented. Low frequency targets generally produce higher amplitude P300s than higher frequency targets. Hence, having low frequency targets may result in better detection of P300, but again, at the cost of longer intervals between cursor movements.

From preliminary analyses, it was determined that the interval from 300 to 600 msec following target onset was the best interval for p300 detection in these subjects. Consequently, we defined a P300 level on each trial to be the maximum signal level in the interval from 300 to 600 msec following target onset.

Results

In general, P300 detection was best for tasks in which target frequency was 0.20 versus 0.25 (54.02% correct and 40.85% respectively averaged across the two subjects who participated in both task conditions). All subsequent results, however, represent data averaged over these two task conditions.

Turning to the issue of the gain in detection accuracy due to summing EEG signals over a sequence of trials, percentage correct direction scores were also calculated for conditions in which one, two, or three successive sets were summed before determining peak P300 amplitudes. Figure 1 shows results of these analyses for the three subjects separately, averaged over all data obtained from each subject. There appears to be a constant increase in percentage correct detection of P300 for each additional trial summed. There is no indication of an interaction among these three subjects.

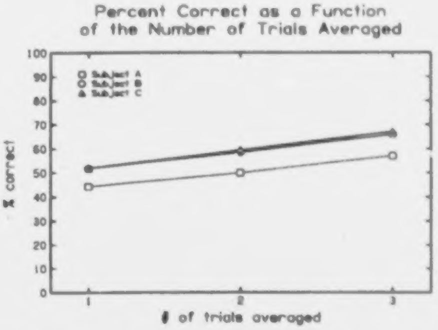
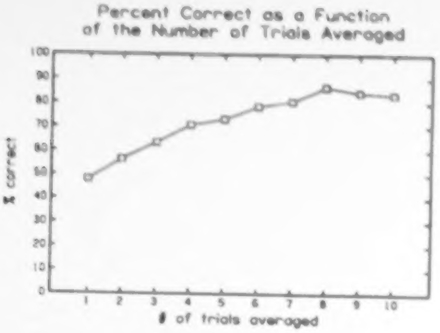


Figure 2 carries this analysis further for one subject (subject A who's performance was lowest overall). In this figure, summation is carried out over up to 9 consecutive trials. As figure 2 shows, the advantages (in percentage correct) of summing trials begins to flatten out after about 6 trials, reaching a level of over 80% correct.



Conclusion

Overall, P300 detection was correct about 50% of the time based on comparisons among peak levels within a single set of trials. Correct detection occurred about 60% of the time when three successive sets of trials were summed before comparing P300 levels. However, this gain of 10 percentage points in correct detection would be accompanied by a factor of three increase in the amount of time necessary to arrive at a decision. Consider how this would effect a subject attempting to move the cursor 10 steps in a particular direction. With 50% accuracy in the P300 detection (and assuming that errors in P300 detection are uniformly distributed over the three unattended targets), the subject would be expected to need 30 steps to reach the goal of ten steps in the attended target direction. These 30 steps, at four seconds per step, would require about 2 minutes of actual time on task. For a 60% accuracy, the expected number of steps to reach a ten-step goal drops to about 21, but at 12 seconds per step, this would require over four minutes to reach the same goal. In no data that we have examined to date have we observed an instance in which the trade-off between accuracy of P300 detection and time would result in advantages for summing trials; the cost in time far exceeds the benefits of accuracy in this task.

Previous work by Farwell and Donchin (1988) on a P300 based communication device concluded that their subjects were able to achieve a communication rate of about 0.20 bits per second. This rate is slightly better than the rates we see in the present data when averaged over all task conditions. Overall average performance for our slowest subject was 0.13 bits per second (44.27% correct) and our fastest subject was 0.18 bits per second (51.92% correct). However, considering only the task in which target frequency was 0.2 for these two subjects, bit rates were 0.15 and 0.27 respectively.

To conclude, we find that averaging over trials in the present task does not appear to be a productive way improve bit rate. However, varying other task variables like target frequency and presentation rate may lead to moderate improvements in the accuracy with which P300 events are detected. In future studies we will continue to explore these and other task variables to find conditions which lead to optimum performance. As a signal for control of communication devices and interfaces, the P300 has several limitations. The most serious of these is the relatively low bit rate associated with its use. However, for some potential users, this low bit rate may still exceed the rates available via other communication channels, and at present, communication rates associated with P300 detection seem equivalent those associated with the detection of other brain events or states

688

References

Duncan-Johnson, C. C., Donchin, E. (1977) On quantifying surprise: the variation of event-related potentials with subjective probability. Psychophysiology, 14, 456-467.

Farwell, L. A. and Donchin, E. (1988) Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. Electroenceph. and Cl. Neurophys., 70, 510-523.

Sutton, S., Braren M., Zubin, J., John, E. R. (1965). Evoked potential correlates of stimulus uncertainty. Science, 150, 1187-1188.

Sutton, S., Tueting P., Zubin J., John E. R. (1967). Information delivery and the sensory evoked potential. Science, 155, 1436-1439.

Tueting, P., Sutton, S., Zubin, J. (1971). Quantitative evoked potential correlates of the probability of events. Psychophysiology, 7, 385-394.

Walter, W. G. (1965) Brain responses to semantic stimuli. Journal of Psychosom. Research, 9, 51-61.

Wolpaw, J.R., McFarland, D.J., Neat, G.W., and Forneris, C.A. (1991) An EEG-based brain-computer interface for cursor control. Electroenceph. and Cl. Neurophys, 78, 252-259.

Acknowledgements

This work was supported by the Nemours Research Programs

Author address

James B. Polikoff
Applied Science and Engineering Laboratories
A. I. duPont Institute
P.O. Box 269
Wilmington, DE 19899
(302)651-6844
e-mail: polikoff@asel.udel.edu

AN EEG-BASED BRAIN-COMPUTER INTERFACE (BCI) SYSTEM USING DIGITAL SIGNAL PROCESSING (DSP) TECHNOLOGY

Dennis J. McFarland, A. Todd Lefkowicz, and Jonathan R. Wolpaw, Wadsworth Center for Laboratories and Research, New York State Department of Health, Albany, NY 12201

ABSTRACT

We have developed a system for training individuals to move a cursor on a video screen by modulating electroencephalographic (EEG) activity recorded from the scalp. This brain-computer interface (BCI) system uses current digital signal processing (DSP) technology operating in parallel with an IBM-compatible personal computer (PC). The major advantages of DSP technology over traditional analog methods are greater reliability and flexibility, and accessibility of full spectral information. Furthermore, the programmable nature of DSP technology facilitates comparisons of alternative signal processing methods.

BACKGROUND

Recently, interest has focused on the potential use of EEG as an alternative means of communication for individuals with severe motor disabilities (1-6). In our approach, individuals learn to use normal EEG rhythms to control a cursor on a video screen.

STATEMENT OF THE PROBLEM

EEG activity is recorded from the scalp over sensorimotor cortex (i.e., locations C3 and C4 of the 10/20 system) amplified and digitized. Its spectral content is determined on-line and the amplitude of the EEG within a specific frequency band is converted to cursor movement on the screen. The user learns to modulate the EEG in order to move the cursor toward a target located at the edge of the screen.

Cursor movement is the output controlled by the EEG because it is easily implemented and quantified, and because it can be used to control a wide range of commercial software. This last consideration is particularly important for applications that would have practical utility for populations with disabilities.

RATIONALE

Many EEG studies and applications have used analog signal processing devices, the characteristics of that are frequently not specified. Analog approaches usually involve band-pass filtering and integration of the EEG signal. Digital algorithms have several advantages over analog techniques. These include greater reliability, accuracy and reproducibility of the analysis, and a greater range of potential solutions to particular processing problems (7). In addition, digital techniques are defined by software rather than by hardware, so that modification and comparison of methods is usually much easier.

This report describes a digital signal processing (DSP)-based brain-computer interface (BCI) system that we have developed to investigate the use of the EEG as a new communication channel for those with severe motor disabilities. It uses a digital signal processor combined with a PC-compatible desktop computer, and converts EEG voltage at specific frequencies to cursor movement on a video screen.

BCI SYSTEM DESIGN

The BCI hardware consists of EEG amplifiers (SA Instruments), analog input boards, a TMS320C30-based floating-point digital signal processing (DSP) board (Spectrum Inc.), and an IBM compatible PC/80486 equipped with two video monitors. An earlier BCI system used the TMS320C25 fixed-point processor (8). Floating-point processors are better because they do not require specialized integer algorithms and can accommodate newer spectral analysis techniques (e.g., the autoregressive method).

The DSP and PC processors are programmed in C and function in a foreground/background mode. They run four processes in parallel. The DSP background process acquires the EEG data and the DSP foreground process performs a spectral analysis. The results are moved to dual-ported memory and an interrupt to the PC is generated. The PC background process acquires these data and controls the display on the user's screen. The PC foreground process provides control parameters for on-line operation, records data to disk, and displays a running summary of the user's performance on the operator's screen.

BCI SYSTEM OPERATION

The user performs a series of trials in which a target appears on the edge of his or her screen, and the task is to move the cursor to the target. If it reaches the target, a hit is registered. If it reaches the edge of the screen at some other point, a miss is registered. Trials typically last 1.5 sec and are grouped into 3-min runs separated by 1-min rest periods.

In the one-dimensional mode, the target appears at either the top or the bottom edge, and vertical cursor movement is a linear function of EEG voltage at C3 at a specific frequency (e.g., 10 Hz) multiplied by a weight (i.e., the system gain) minus the mean voltage from past performance also multiplied by the gain. Thus, if y is the vertical cursor movement, V_{C3} is the EEG voltage at C3 at 10 Hz, b is the gain, and a is the mean voltage, the function that determines cursor movement is: $y = b\ (V_{C3} - a)$. If a is stable, net cursor movement over an extended period will be zero and targets at the top and bottom edges of the screen will be equally accessible to the user. The value of b determines the rate of cursor movement.

In the two-dimensional mode, a target appears in one of the four corners of the user screen. One linear function controls horizontal cursor movement and another controls vertical movement. At present, we use the sum of the 10-Hz voltages at C3 and C4 to control horizontal movement and their difference to control vertical movement (6). If y_v is vertical cursor movement, y_h is horizontal cursor movement, and V_{C3} and V_{C4} are voltages at specific scalp locations and frequencies: $y_v = b_v\ (V_{C3} + V_{C4} - a_v)$ and $y_h = b_h\ (V_{C4} - V_{C3} - a_h)$ are the functions that determine cursor movement. Ideally, y_v and y_h are orthogonal.

If users are to control cursor movement, two requirements must be met. First, they must develop control over the EEG voltages in the equations shown above. Second, a and b must be properly chosen. The value of a, the mean voltage, is computed between 3-min runs as the average of its previous value and the mean voltage of the run just completed. The proper selection of b, the gain, is more complex. We use an algorithm that sets b so that the average trial duration approaches a chosen value (e.g., 2 sec).

Data needed for computing a and b are recorded by the PC background process while the user is moving the cursor. The PC foreground process calculates a and b in the 1-min rest periods between runs. The PC background process stores the data in buffers, and its foreground process transfers the data to disk at appropriate intervals. In addition, the state of the system at each PC background cycle is transmitted through a serial port to a second computer that operates in parallel. This second computer simply stores raw EEG from 64 scalp locations and system state for later analysis aimed at defining improved methods for controlling cursor movement on-line.

USER TRAINING AND PERFORMANCE

For each user, training begins with the one-dimensional version of the task and the gain of the system is low so that cursor movement is slow. As training progresses and the user acquires more control, the gain is increased so that the cursor moves faster. At the beginning of two-dimensional training, each corner target occupies a large portion of the edge of the screen (e.g., 40%). As two-dimensional training progresses, target size is gradually decreased so that it eventually occupies only 25% of the edge.

By the end of one-dimensional training, users typically achieve accuracies of >90%, i.e., the cursor reaches the correct edge of the screen on more than 9 of 10 trials. The EEG control achieved is illustrated in Figure 1A, which compares the spectra at location C3 for top and bottom targets. Control is clearly focused in the 8-12 Hz mu rhythm band and its related 16-24 Hz beta band.

Current efforts to further improve cursor accuracy are taking advantage of the flexibility of the DSP-based design. While the accuracy achievable for two-dimensional cursor movement remains to be defined, results show that users can learn simultaneous independent control of amplitude at two scalp locations and thus satisfy the requirements for two-dimensional control (6).

BCI SYSTEM ADVANTAGES

DSP technology provides the entire spectrum of the EEG. In contrast, analog techniques usually provide only one or a few spectral bands. This capacity greatly aids detection of non-EEG artifacts that can interfere with or masquerade as EEG-based cursor control. Such artifacts can be produced by EMG (muscle) activity, eye blinks, eye movements, or movements of the head and neck. They can be distinguished from EEG by their spectral content (2). As noted above, Figure 1A shows spectra from a user performing the one-dimensional task. EEG control is limited to narrow bands centered at 10 Hz and 20 Hz. In contrast, the effect of jaw clenching (1B) is broadbanded and increases with frequency, and the effect of eye blinking (1C) is greatest at 1-4 Hz and absent above 10 Hz. Analyzed in this comprehensive way by DSP technology, neither artifact can be mistaken for EEG control.

The DSP-based BCI system can also prevent artifacts from affecting cursor movement by specifying maximum allowable voltages for specific frequency bands. If these values are exceeded, no cursor movement occurs and an artifact is registered. By this means, artifacts like eye blinks or EMG are prevented from contributing to cursor movement.

In addition to its stability, reliability, and adaptability, the DSP-based BCI system can easily incorporate technological advances. Our first system had a 80286-based PC and a fixed-point DSP. Our present system, with a 80486-based PC and a floating-point DSP, has much greater processing power. Nevertheless, the basic software design has not required change. The greater processing power permits additional on-line procedures such as autoregressive spectral analysis. Future developments in digital technology should allow still more sophisticated real-time analysis of the EEG and support more rapid and accurate brain-computer communication.

REFERENCES

1. Farwell LA, Donchin E (1988) Talking off the top of your head: Toward a mental prothesis utilizing event-related brain potentials. *Electroencephalogr clin Neurophysiol* 70:510-523.
2. Wolpaw JR, McFarland DJ, Neat GW, Forneris CA (1991) An EEG-based brain-computer interface for cursor control. *Electroencephalogr clin Neurophysiol* 78:252-259.
3. McFarland DJ, Neat GW, Read RF, Wolpaw JR (1993) An EEG-based method for graded cursor control. *Psychobiol* 21:77-81.
4. Pfurtscheller G (1992) Bewegungssteuerung mit Hilfe des EEG:Grundlagen fur ein Brain-Computer-Interface. *TW Neurologie Psychiatie* 6:834-841.
5. Sutter EE (1992) The brain response interface: communication through visually-induced electrical brain responses. *J Microcomp App* 15:31-45.
6. Wolpaw JR, McFarland DJ (1994) Multichannel EEG-based brain-computer communication. *Electroencephalogr clin Neurophysiol* 90:444-449.
7. Stearns SD, David RA (1988) *Signal Processing Algorithms*, Prentice-Hall, Englewood Cliffs, NJ.
8. Neat GW, McFarland DJ, Forneris CA, Wolpaw JR (1990) EEG-based brain-to-computer communication: system description. *Proc IEEE Med Biol* 5:2298-2300.

ACKNOWLEDGEMENTS

This work was supported by the National Center for Medical Rehabilitation Research, NICHD, NIH (HD30146).

Dennis J. McFarland
Wadsworth Center for Laboratories and Research
New York State Department of Health
Empire State Plaza, Box 509
Albany, NY 12201-0509 USA
(518) 486-2677, 473-3631

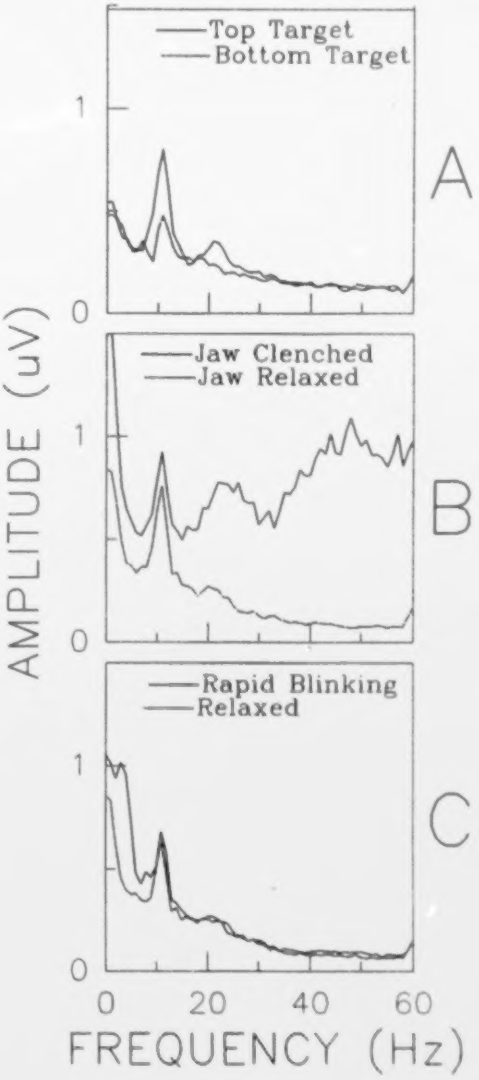


Figure 1. Fourier transform-based spectra at location C3 for one user. In A, the user was controlling cursor movement to top or bottom targets. B shows the effect of jaw clenching and C shows the effect of eye blinking. Only A shows the narrow-banded difference typical of EEG control.

DEVELOPMENT OF DIRECT BRAIN-COMPUTER COMMUNICATION IN A PERSON WITH AMYOTROPHIC LATERAL SCLEROSIS

Lynn McCane, Theresa M. Vaughan, Dennis J. McFarland, and Jonathan R. Wolpaw, Wadsworth Center for Laboratories and Research, New York State Department of Health, Albany, NY 12201

ABSTRACT

Recent studies suggest that brain-computer interface (BCI) technology can provide a new communication channel for those with severe motor disabilities (1-4). In the present study, a man with amyotrophic lateral sclerosis learned to use EEG activity over sensorimotor cortex to control cursor movement on a video screen. His development of control was facilitated by off-line topographic and frequency analysis of EEG data recorded during training. This analysis led to improvements in the on-line algorithm that converted EEG activity into cursor movement and enabled the user to move the cursor more rapidly and accurately. BCI technology might be an alternative communication option for those with ALS that could be mastered early in the disease and continue to serve even after muscular function is lost.

BACKGROUND

Amyotrophic lateral sclerosis (ALS or Lou Gehrig's disease) is a progressive disease of upper and lower motoneurons that leads to paralysis and death from respiratory failure. Those individuals who elect to survive on ventilators may progress to total paralysis and loss of all means of communication. They need a communication channel that does not depend on muscular function.

Our laboratory is developing non-invasive brain-computer interface (BCI) technology as an alternative means of communication for those who lack muscular control (1-3). People learn to use specific components of electroencephalographic (EEG) activity recorded from the scalp to control movement of a cursor on a video screen. Cursor movement serves as the prototype for a wide variety of possible applications for this new communication channel. Present efforts are directed at improving the algorithm that converts EEG activity into cursor movement, improving user training methods, and applying BCI technology for use by those with motor disabilities.

The present report describes development of BCI capability in a person with ALS. This development included both the gradual acquisition of EEG control by the user and successive improvements in the algorithm that converts EEG control into cursor control. These two processes proceeded in parallel and together led to highly accurate cursor control.

USER

CS is a 67-year-old man who was diagnosed with ALS four years ago in October of 1990. His disease has progressed slowly, and his current symptoms are lower left quadrant atrophy and muscle fatigue. He takes medication for hypertension. He began participating in our BCI development program in February 1994. He gave informed consent for the study, which had been reviewed and approved by the New York State Department of Health Institutional Review Board.

OBJECTIVE

The objective of this study was to train CS to control one-dimensional cursor movement accurately enough to hit a target located at the top or bottom edge of a video screen greater than 90% of the time.

METHODS

BCI methodology and procedures, which are fully described in our previous publications (1-3), are summarized here. CS sat in a reclining chair about 3 meters from a video screen and wore an Electro-cap that recorded 64 channels of EEG from the scalp (5). The signals were all referenced to the right ear. They were amplified (bandpass 1-35 Hz, 20,000X) and digitized by two PC systems. One system stored all 64 channels at 128 Hz for later analysis. The other performed a spectral analysis on one or two selected channels and translated the amplitudes in specific frequency bands to cursor movement on the video screen in front of CS.

CS completed 2-3 sessions per week. Each session consisted of 8 3-minute runs separated by one-minute breaks. Each run included a series of trials (25-35 per run) in which a target appeared at the top or bottom edge of the screen and the cursor appeared in the center. The cursor moved vertically under EEG control until it touched the edge of the screen. If the cursor touched the edge occupied by the target, the target flashed and a hit was

692

registered. If it touched elsewhere, a miss was registered. In either case, a brief pause ensued followed by another trial.

In accord with our standard practice (1-3), we began by basing cursor movement on activity over left sensorimotor cortex (i.e., location C3 (5)). Two common components of activity in this region are the 8-12 Hz mu rhythm and the 16-24 Hz beta rhythm (6). In the case of CS, initial evaluation indicated that the beta rhythm was more prominent than the mu rhythm. Thus, we began BCI training for CS by using 15-21 Hz amplitude at C3 to control vertical cursor movement. As training progressed, we conducted off-line analysis of the stored 64-channel data. As described in the next section, the results of this detailed frequency and topographic analysis were used to modify the algorithm that converted EEG into cursor movement.

RESULTS

Figure 1 summarizes the development of CS's one-dimensional control. Even in the first session he displayed significant control, since accuracy was considerably higher than the 50% expected by chance. Over the first 10-15 sessions, accuracy rose to 70-75%, and then remained about the same through session 30. During this period, the slope of the equation that converted EEG amplitude to cursor movement was gradually increased, so that average trial duration fell to about 1.5 sec. At session 21, the frequency band was changed to 18-22 Hz. At session 29, the channel used to control cursor movement was changed from C3-right ear to C3-common average reference (CAR) and accuracy quickly rose to 75-85%. It continued to rise slowly over the next 30 sessions, at which point the fast Fourier transform (FFT) frequency analysis used in the on-line algorithm was replaced by the maximum entropy method (MEM). MEM frequency analysis allowed us to decrease the length of the time segment subjected to analysis without decreasing frequency resolution. Accuracy continued to rise gradually until the cursor movement rate was increased from 4 to 8 movements/sec in session 73 and then to 16 movements/sec in session 77. Accuracy then increased to 85-95%. Finally, at session 82, control of cursor movement by C3-CAR was changed to control by the sum of C3-CAR and C4-CAR (i.e., sum of 18-22 Hz activity over left and right sensorimotor cortices). This change was suggested by topographic analysis indicating that EEG control was present at both locations. Accuracy was 90-95% for the final one-dimensional sessions, and thus achieved the objective of the study (i.e., ≥90% accuracy). At that point, CS began two-dimensional BCI training. This second phase of his training is still underway.

Figures 2 and 3 illustrate the spectral and topographical specificity of the EEG control achieved by CS. Figure 2A shows C3+C4 spectra for top and bottom targets. Control is focused in a narrow band around 20 Hz. This is further shown in 2B by the graph of r^2, the coefficient of determination, which is the percent of the total variance that is ascribable to target location. Figure 3 shows the topography of r^2 at 20 Hz. Control is focused over sensorimotor cortex of both hemispheres.

DISCUSSION

In this study, a person with ALS learned to use EEG over sensorimotor cortex to control cursor movement with a high degree of accuracy. This control developed over a lengthy series of training sessions. The prolonged course of development appears to have been a result of two factors. One factor was the series of improvements made in the algorithm that converted EEG into cursor movement. These were: the common average reference, MEM frequency analysis, higher cursor movement rate, and the sum of C3 and C4. These changes were instituted at intervals so that we could see their effects. Had they been in use from the start, the final high level of accuracy would probably have been achieved considerably earlier. The other factor contributing to the progressive increase in accuracy was the user's gradual acquisition of EEG control. Like other skills, EEG control improves with practice. This is evident in Figure 1 in the gradual improvements seen between sessions 1 and 29 and sessions 30 and 55. The effect of this practice suggests that, while earlier improvements in the algorithm would have led to higher accuracy earlier, achievement of ≥90% accuracy would still have required some weeks of training.

Individuals with ALS often progress through a series of assistive devices as their disability increases. BCI technology might supply a new alternative that could be mastered early and continue to serve even after all useful muscular function was lost. At the same time, it remains to be determined whether ALS, which may affect upper as well as lower motoneurons, will eventually impair EEG control. This issue will be resolved by study of those in more advanced stages of the disease.

REFERENCES

1. Wolpaw JR, McFarland DJ, Neat GW, and Forneris CA (1991) An EEG-based brain-computer interface for cursor control. *Electroencephalogr Clin Neurophysiol* 78:252-259.

2. McFarland DJ, Neat GW, Read RF and Wolpaw JR (1993) An EEG-based method for graded cursor control. *Psychobiol* 21:77-81.

3. Wolpaw JR and McFarland DJ (1994) Multichannel EEG-based brain-computer communication. *Electroencephalogr Clin Neurophysiol* 90:444-449.

4. Pfurtscheller G, Flotzinger D and Kalcher J (1993) Brain-computer interface-a new communication device for handicapped persons. *J Microcomp Appl* 16:293-299.

5. Sharbough F and others (1991) American Electroencephalographic Society Guidelines for Standard Electrode Position Nomenclature. *J Clin Neurophysiol* 8:200-202.

6. Pfurtscheller G (1981) Central beta rhythm during sensorimotor activities in man *Electroencephalogr Clin Neurophysiol* 51:253-264.

ACKNOWLEDGEMENTS

Supported by Natl Ctr for Medical Rehabilitation Research, NICHHD, NIH (HD30146).

Lynn McCane
Wadsworth Center for Laboratories and Research
New York State Department of Health
Empire State Plaza, P.O. Box 509
Albany, New York 12201-509 USA
518-486-2677
e-mail: mccane@wadsworth.org

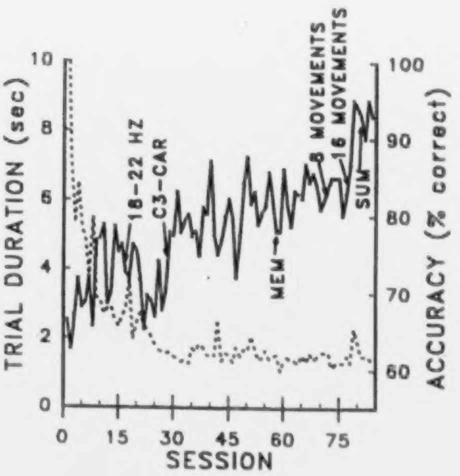


Figure 1. Development of control over vertical cursor movement. The dotted line shows trial duration and the solid line shows the percent correct. Arrows indicate changes in the on-line algorithm as described in the text.

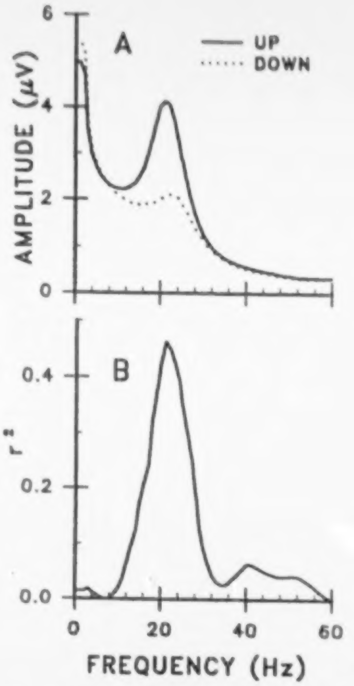


Figure 2. Spectral analysis of C3+C4 for CS's last session of one-dimensional training. A. Spectra for the up (solid) and the down (dotted) targets. Control is clearly found in a band centered at 20 Hz. B. The spectrum of r^2 for the same data set shows comparable narrow-banded control.

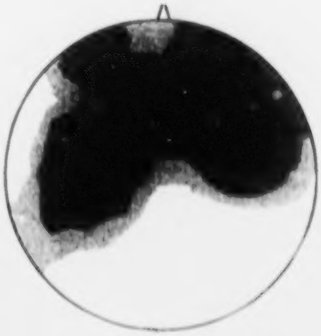


Figure 3. Average r^2 at 20 Hz for CS's last five sessions of one-dimensional training. The head is viewed from above. The nose is at the top. The lightest level is below 0.13 and the darkest is at least 0.28. Control is centered near C3 and C4 (X's).

IMPROVEMENT IN EEG-BASED BRAIN-COMPUTER COMMUNICATION BY USE OF ADDITIONAL RECORDING LOCATIONS

M. Jameson Foster, Dennis J. McFarland, A. and Jonathan R. Wolpaw, Wadsworth Center for Laboratories and Research, New York State Department of Health, Albany, NY 12201

ABSTRACT

Our previous studies indicate that humans can learn to control cursor movement by modulating EEG activity recorded over sensorimotor cortex. The present study tests the hypothesis that incorporation of EEG from additional scalp locations into the algorithm that controls cursor movement can improve movement accuracy. It uses a logistic regression model to evaluate the impact of EEG from additional locations. The results indicate that use of EEG from a small number of additional locations could significantly reduce the error rate of cursor control. This improvement would increase the likelihood that brain-computer interface (BCI) technology will be able to provide a valuable new communication channel for those with severe motor impairments. Further application of the analysis methods developed here may lead to further improvements in BCI capability.

BACKGROUND

Recent studies from this laboratory have shown that humans can learn to control EEG activity over sensorimotor cortex and use this control to move a cursor from the center of a video screen to a target on the edge (1-3). We are developing this brain-computer interface (BCI) technology into a new communication channel for those with severe motor disabilities. Our goal is to achieve mouse-like control, so that BCI technology can access the large number of mouse-driven programs now available.

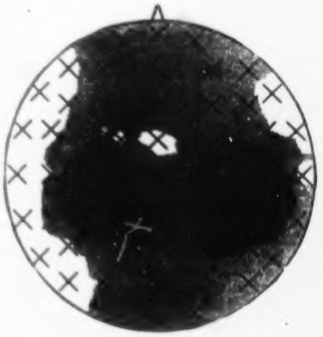
Our first studies (1,2) used 8-12 Hz mu rhythm activity from one location over sensorimotor cortex of one hemisphere and controlled one dimensional (i.e., vertical) cursor movement. A subsequent study (3) used mu rhythm activity from two locations (i.e., sensorimotor cortex of each hemisphere) and controlled two-dimensional cursor movement. Current studies are seeking to improve the accuracy and rate of one and two-dimensional cursor movement. The hypothesis underlying this work is that use of EEG activity from additional scalp locations and/or in additional frequency bands can improve control. To evaluate this hypothesis, we are storing EEG recorded from 64 scalp locations while people use the current BCI system to control cursor movement. We are analyzing these data off-line to determine better methods for controlling cursor movement on-line.

RESEARCH HYPOTHESIS

This study analyses data gathered while users were using the sum of mu rhythm recorded over sensorimotor cortex of both hemispheres (i.e., locations C3 and C4 (4)) to control vertical cursor movement to a target at either the top or bottom edge of a video screen. It tests the hypothesis that movement would have been more accurate if it had been determined not just by the sum of C3 and C4 but by an appropriate combination of C3, C4, and one or more of the 8 locations closest to them (i.e., the 4 around C3, and the 4 around C4).

Figure 1 is an example of the evidence for this hypothesis. A user who had mastered one-dimensional control is using the sum of mu rhythm amplitudes at C3 and C4 to control vertical cursor movement. Figure 1 shows the topography (from above the head, nose at top) of the difference in the mu rhythm frequency band between trials with top and bottom targets (expressed as r^2, the percent of the total variation accounted for by the target). EEG control is evident at C3 and C4 (heavy X's), and nearby locations. Such data suggest that a combination derived from all these locations might give better cursor control than C3 and/or C4 alone.

Figure 1.



METHOD

To address this question, we began with the 64-channel EEG data from two daily sessions from each of four experienced users (3 men, 1 woman, ages 29, 30, 40, and 66). Three were without disability and one was disabled by the early stage of amyotrophic lateral sclerosis (ALS). Each session contained 210-331 individual trials in each of which a target appeared at the top or bottom edge of the screen and the cursor began in the center and moved vertically in response to the user's EEG until it reached the target (i.e., a hit) or reached the other edge of the screen (i.e., a miss).

To test the hypothesis that additional locations would provide better cursor control, we evaluated these data in four steps. First, we applied the maximum entropy spectral analysis method to each 200-msec segment from each of the 10 locations (i.e., C3, C4, and the 4 locations closest to each) and determined the amplitude in the frequency bin that had been used to control cursor movement on-line (e.g., a 4-Hz wide bin centered at 12 Hz). Second, for each location, the mean result for each trial and the grand mean result for the entire session were calculated, and the grand mean was subtracted from the trial mean to give a final value for each trial. Third, we used a logistic regression model (5) to predict whether a top or bottom target had been presented in the trial. This generalized linear model uses one or more covariates to predict the log of the odds of the occurrence of a (0, 1) variable. In this application, the covariates are the trial values for the electrode locations and the event predicted is the occurrence of a top target. The model implies a curvilinear relationship between the covariates $(x_1, x_2, .. x_n)$ and the probability, $\pi(X)$, predicted from them. It gives for each trial the probability that the target is at the top of the screen:

$$\pi(X) = \exp(\alpha + \sum\beta_i x_i) / (1 + \exp(\alpha + \sum\beta_i x_i)).$$

It is clear that $\pi(X) \rightarrow 1$ as $\sum\beta_i x_i \rightarrow \infty$ and $\pi(X) \rightarrow 0$ as $\sum\beta_i x_i \rightarrow -\infty$. With the SAS logistic procedure, we determined for each trial the probability predicted by combinations of one or more locations. A probability of ≥ 0.5 was defined as a prediction of a top target and a probability of < 0.5 was defined as a prediction of a bottom target. We then determined the percent of trials in the session for which the prediction was correct. A step-wise selection procedure was used to determine for each session of each user which combination of up to all 10 locations gave the highest accuracy. Finally, because on-line and off-line accuracies cannot be compared directly (since on-line and off-line processing differ in artifact elimination and the effect of trial duration), the on-line accuracy that would have been achieved with each combination of locations was estimated by dividing its percent correct by that of locations C3 + C4, the combination used on-line, and multiplying the result by the percent correct that C3+C4 actually achieved on-line.

RESULTS

Table 1 below summarizes the results. It shows in percent the on-line accuracy actually achieved by C3 and C4, and the on-line accuracies predicted for C3, the location used in our initial studies (1,2), and for the best combination of the 10 locations analyzed here. Values are shown for both sessions from each user. Means and standard deviations for all sessions are also shown. Depending on the user and session, the best combination comprised from 2 to 7 locations.

Table 1. Session accuracies in percent.

Locations	C3	C3+C4	Best Comb
User A	88/87	93/88	96/92
User B	77/81	94/92	100/93
User C	92/91	94/93	95/93
User D	90/91	95/93	96/100
Mean(SD)	87(6)	93(2)	96(3)

For users A, B, and D, C3+C4 gives better results than C3 alone and the best combination gives better results than C3+C4. For user C, C3+C4 appears only slightly better than C3 and as good as the best combination. For every session analyzed, C3+C4 was significantly better than C3, and for 7 of the 8 sessions the best combination was significantly better than C3+C4 ($P<0.001$ by chi-square test). For the remaining session, C3+C4 was the best combination. Overall, the progression from C3 to the best combination reduces error frequency by more than two-thirds, from 13% to 4%.

DISCUSSION

The results indicate that use of additional electrode locations could substantially improve the accuracy of EEG-based brain-computer communication. Our present BCI system can incorporate such combinations in the algorithm that controls cursor movement on-line. The improvement projected here, from 87% with C3 alone, or 93% with C3+C4, to 96% with the best possible combination, could allow this new communication channel to make the transition from a significant laboratory phenomenon to a technology of significant practical value for those with severe motor impairments.

If a combination of electrode locations is to be preferable for on-line control, then it must give consistent performance over time, i.e., over multiple sessions. The present evaluation, comprising two sessions from each user, gives some initial insight into this crucial issue. As Table 1 shows, C3+C4 is clearly better than C3 alone in both sessions from each user. This finding is consistent with our observation that accuracy usually increases markedly when cursor movement control is switched from C3 to C3+C4. The additional advantage conferred by the best combination is less defined. While for each user the best combination for one session was similar to that for the second session, the two were not identical. Thus, further analysis involving data from many sessions and identical application of specific combinations to all sessions is necessary to define fully the benefit of additional locations and the best methods for realizing it on-line. In this regard, it should be noted that the on-line algorithm could be modified to incorporate periodic recalculation of the best possible combination. Finally, it must be remembered that, because the user's performance adjusts over time to the algorithm that controls cursor movement, the effectiveness of any combination derived from off-line analysis can be determined with complete certainty only by applying it on-line.

This analysis focused on electrode locations immediately surrounding C3 and C4 and on a single frequency band. Further evaluations are needed to address the usefulness of more distant electrode locations and/or other frequency bands. Related studies (3,6,7) suggest that such locations or frequencies may furnish access to other controllable EEG components and thereby support further improvements in the speed and accuracy of EEG-based brain-computer communication. These evaluations are now underway. They are incorporating and extending the off-line analysis procedures developed and tested in the present study.

REFERENCES

1. McFarland, D.J., Neat, G.W., Read, R.F. and Wolpaw, J.R. (1993) An EEG-based method for graded cursor control. *Psychobiol*, 21, 77-81.

2. Wolpaw, J.R., McFarland, D.J., Neat, G.W. and Forneris, C.A. (1991) An EEG-based brain-computer interface for cursor control. *Electroencephalogr clin Neurophysiol*, 78, 252-259.

3. Wolpaw, J. R. and McFarland, D. J. (1994) Multichannel EEG-based brain-computer communication. *Electroencephalogr clin Neurophysiol*, 90, 444-449.

4. Sharbrough, F., Chartrian, G. E., Lesser, R. P., Lüders, H., Nuwer, M., and Picton, T.W. (1991) American Electroencephalographic Society guidelines for standard electrode position nomenclature. *J Clin Neurophysiol*, 8, 200-202.

5. Agresti, A. (1990) *Categorical Data Analysis*. Wiley-Interscience.

6. Pfurtscheller, G. (1989) Functional topography during sensorimotor activation studied with event-related desynchronization mapping. *J Clin Neurophysiol*, 6, 75-84.

7. Pfurtscheller, G. and Berghold, A. (1989) Patterns of cortical activation during planning of voluntary movement. *Electroencephalogr Clin Neurophysiol*, 72, 250-258.

ACKNOWLEDGEMENTS

This work was supported by the National Center for Medical Rehabilitation Research, NICHD, NIH (HD30146).

M. Jameson Foster
Wadsworth Center for Laboratories and Research
New York State Department of Health and
State University of New York
Box 509, Empire State Plaza
Albany, NY 12201-0509 USA
(518) 486-2677, 473-3631

GRAZ BRAIN-COMPUTER INTERFACE II: STUDIES FOR AN EEG-BASED COMMUNICATION DEVICE

Joachim Kalcher, Doris Flotzinger, Gert Pfurtscheller, Silvia Gölly, Christa Neuper
Institute of Biomedical Engineering, Department of Medical Informatics, and Ludwig Boltzmann-Institute of Medical Informatics and Neuroinformatics, Graz University of Technology, Graz, Austria

ABSTRACT

This paper describes the setup of the Graz Brain-Computer Interface (BCI) system II, which is based on on-line classification of EEG patterns produced while subjects prepare for three kinds of movement. These classification values can be exploited for information exchange from the brain to the computer and may thus constitute a great help for severly handicapped persons in the future.

BACKGROUND

A system which uses EEG to build a communication line between the brain and an electrical appliance has become known as a Brain-Computer Interface (BCI). Several teams all over the world are currently working at such systems [1-4]. This paper describes the work done in Graz, a system which is mainly based on the discrimination of various types of electrical brain activity patterns related to movement planning [3, 4].

It is known since the work of Jaspers and Penfield [5] that planning or preparation of movement results in a desynchronization of rhythms within the alpha and beta bands. Quantification of event-related desynchronization (ERD) has shown that preparation of right hand, left hand and foot movement results in different ERD patterns with the maximal desynchronization being localized over primary sensorimotor areas [6, 7]. Based on these results a system was designed which is able to analyse and classify ERD patterns on-line when the subject „thinks" of right hand, left hand or foot movement.

This paper reports on experiments with the Graz BCI II system where the goal was to distinguish between three EEG patterns. The performance achieved in 4 subjects on-line is compared to off-line analyses of the data which show that classification performance can be improved when narrow frequency bands in the alpha and beta bands are selected and used for classification.

METHOD

Experimental Paradigm & Recording Scheme

The basics of a trial of the Graz BCI II are shown in Fig. 1. The subject is seated in a comfortable chair looking at a fixation cross on a monitor 1 meter in front of the subject's eyes. One second after an acoustic warning stimulus ('beep') a cue in the form of an arrow, pointing either left, right or down, appears and indicates to the subject that he should either press a microswitch with his left index finger, his right index finger or move the toes of his right foot upwards (dorsal flexion), respectively, after the arrow vanishes. A 1-sec period starting 250 msec after presentation of the cue is classified into one of the three movement tasks and the result is fed back to the subject either as '+' (i.e., the requested movement type could be correctly identified), 'o' (i.e., the classifier derived an ambiguous result) or '–' (i.e., the data of the current trial were identified as a movement task different to the one requested).

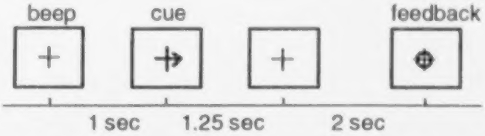


Fig. 1. Experimental paradigm of the Graz BCI II

A PC486 with a DSP-board records and classifies the EEG and provides the subject with the feedback. Three bipolar EEG channels are recorded and interpreted by on-line classification: C_3-C'_3, C_z-C'_z and C_4-C'_4 (C_3, C_z and C_4 according to the international 10-20 system, C_3', C_z' and C_4' 5 cm posterior to C_3, C_z and C_4, respectively, see Fig. 2). The signals are sampled at 64 Hz. The features extracted from the 1-second period of EEG and presented to the classifier are comprised of four power estimates, each representing 250 msec, per EEG channel. Based on these 12 features/trial (3 EEG channels times 4 power estimates) the classifier derives a classification plus a measure describing the certainty with which this classification was obtained. This certainty measure allows the identification of ambiguous results which are then fed back to the subject as 'o' (see above).

Four subjects (1 female and 3 male students aged between 23 and 27 years) participated in four (subjects A6 and B8) and five (subjects B9 and A1) experimental sessions each within 2 weeks. Each session lasted about 1.5 h and comprised four blocks of 60 trials each, with 5 min breaks between blocks. In the first session, data were collected for the creation of a subject-specific classifier and, therefore, no feedback was provided. In the following sessions 2 and 3, the classifier was used to classify the

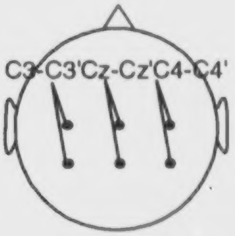


Fig. 2. Positions of the electrodes on the scalp

subject's EEG on-line while he prepared for one of the three kinds of movement and feedback was given to the subject as described above. In sessions 4 and 5 subjects were instructed to suppress actual motor ouput, they were asked to concentrate on the corresponding body part instead.

Classification Method

The classifier used in the Graz BCI II system is a Learning Vector Quantizer (LVQ) [8, 9]. Basically, a LVQ is a nearest-neighbour classifier which generates a labelled codebook in such a way that for each training example the nearest codebook vector is of the same category as the given example. Thereby, LVQ tries to optimize the representation of the training examples by the codebook vectors (also known as Vector Quantization) and at the same time to minimize the classification error. The labelled codebook is generated using an iterative learning procedure where in each iteration a randomly selected training example of known classification is compared to the codebook and the two closest codebook vectors are found. Depending on the class labels of the given example and of the two codebook vectors the latter two are updated by either pushing them towards the example (if the class labels are identical to the known classification of the example, i.e., classification was correct) or pushing them away from the example in the case of incorrect classification (for a detailed description of the algorithm see [8, 9]). The overall aim of this learning algorithm is to increase the probability of correct classification the next time the same example is presented.

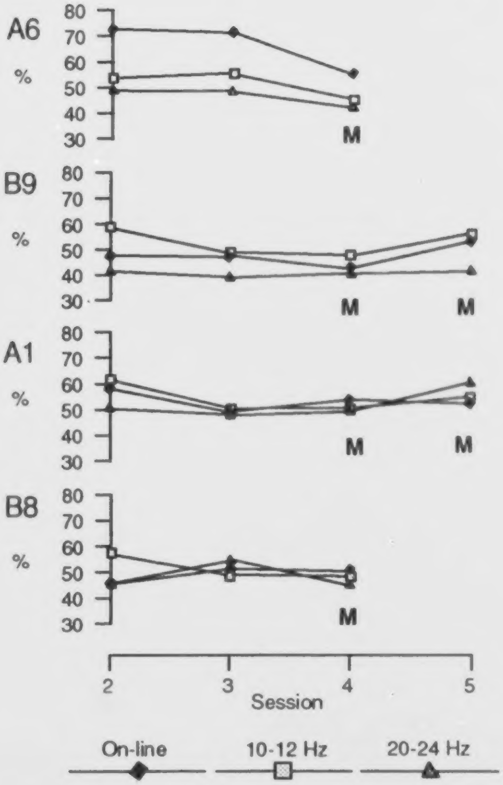


Fig. 3. Comparison of on-line and off-line results

RESULTS

The following results show the accuracies achieved on-line plus the classification performance of off-line analyses, which were made to determine whether filtering the EEG data in specific frequency ranges known to be modulated before and during movement, namely alpha (10-12 Hz) and beta (20-24 Hz) bands, might improve results. Fig. 3 shows the results achieved in 4 subjects over sessions, where an 'M' marks sessions without motor ouput. In three out of four subjects both the alpha and the beta band seem to contain the major part of information since the classification performances are comparable to the results achieved on-line on data containing frequencies between 5 and 35 Hz.

DISCUSSION

The results given in Fig. 3 promise at least two possibilities for future experiments:

(i) On-line filtering of EEG in the alpha and/or beta band might improve or, at least, stabilize performance. The drop of results from session 3 to session 4, the first session without actual motor output, was not as prominent in the off-line analyses as on-line.

(ii) The idea to train subjects by instructing them to perform a small set of movements for some sessions and then suppress actual motor output and restrict themselves to imagery of the requested movement seems to be useful since the results achieved on-line in sessions 4 and 5 are clearly above random. The upward tendency from session 4 to 5 suggests an investigation whether further sessions without motor output will give increasingly better results.

REFERENCES

1. Wolpaw J. R., McFarland D., Neat G. W., Forneris C. A.: An EEG-based brain-computer interface for cursor control, Electroenceph. and clin. Neurophysiol., Vol. 78, pp. 252-259, 1991.
2. McFarland D. J., Neat G. W., Read R. F., Wolpaw J. R.: An EEG-based method for graded cursor control, Psychobiology, Vol. 21, No. 1, pp. 77-81, 1993.
3. Pfurtscheller G., Flotzinger D., Kalcher J.: Brain-Computer Interface - a new communication device for handicapped persons, Journal of Microcomputer Appl., Vol. 16, pp. 293-299, 1993.
4. Pfurtscheller G., Flotzinger D., Neuper Ch.: Differentiation between finger, toe and tongue movement in man based on 40-Hz EEG, Electroenceph. and clin. Neurophysiol., Vol. 90, pp. 456-460, 1994.
5. Jasper H.H., Penfield W.: Electrocorticograms in man: effect of voluntary movement upon the electrical activity of the precentral gyrus, Arch. Psychiat. Z. Neurol., Vol. 183, pp. 163-174, 1949.
6. Pfurtscheller G., Berghold A.: Patterns of cortical activation during planning of voluntary movement, Electroenceph. and clin. Neurophysiol., Vol. 72, pp. 250-258, 1989.
7. Pfurtscheller G., Pregenzer M., Neuper Ch.: Visualization of sensorimotor areas involved in preparation for hand movement based on classification of μ and central β rhythms in single EEG trials in man, Neuroscience Letters, Vol. 181, pp. 43-46, 1994.
8. Kohonen T.: The Self-Organizing Map, Proceedings of the IEEE, Vol. 78, No. 9, pp. 1464-1480, 1990.
9. Flotzinger D., Kalcher J., Pfurtscheller G.: EEG Classification by Learning Vector Quantization, Biomedizinische Technik, Vol. 37, No. 12, pp. 303-309, 1992.
10. Pfurtscheller G., Flotzinger D., Mohl W., Peltoranta M.: Prediction of the side of hand movements from single-trial multi-channel EEG data using neural networks, Electroenceph. and clin. Neurophysiol., Vol. 82, pp. 313-315, 1992.
11. Flotzinger D., Pregenzer M., Pfurtscheller G.: Feature Selection with Distinction Sensitive Learning Vector Quantisation and Genetic Algorithm, Proceedings of IEEE conference on Neural Networks (ICNN 94), pp. 3448-3451, 1994.

ACKNOWLEDGEMENTS

This work was supported by the "Fonds zur Förderung der wissenschaftlichen Forschung", project P9043, and the "Allgemeine Unfallversicherungsanstalt (AUVA)".

Prof. Dr. Gert Pfurtscheller
Institute of Biomedical Engineering
Department of Medical Informatics
Graz University of Technology
Brockmanngasse 41
A-8010 Graz / Austria / Europe
Tel.: (+316) 82 16 94
Fax: (+316) 81 29 64
email: pfu@dpmi.tu-graz.ac.at

DIRECT BRAIN INTERFACE UTILIZING SELF-REGULATION OF STEADY-STATE VISUAL EVOKED RESPONSE (SSVER)

Grant R. McMillan and Gloria L. Calhoun
Armstrong Laboratory (AL/CFHP), Wright-Patterson Air Force Base, OH
Matthew S. Middendorf, Symvionics, Inc., Dayton, OH
John H. Schnurer, David F. Ingle, and Victoria T. Nasman, Logicon Technical Services, Inc., Dayton, OH

ABSTRACT

Brain actuated control is an innovative way to operate systems traditionally controlled by physical interactions. The direct brain interface described in this paper uses the magnitude of the steady-state visual evoked response (SSVER) as a control signal. The SSVER is identified and monitored using non-invasive scalp electrodes and advanced signal processing technology. With biofeedback, human subjects learn to increase or decrease the magnitude of the SSVER. These responses are translated into commands that control the operation of a physical device or computer program. After further development, this enabling technology may allow individuals with severe disabilities to control computers, prosthetic limbs, wheelchairs or home systems.

BACKGROUND

Research spanning three decades has demonstrated operant conditioning of numerous aspects of animal and human electroencephalographic (EEG) and neural evoked responses (1,2). Animal studies have demonstrated specific conditioning of brain activity, independent of skeletal muscle responses or other artifacts (2). Biofeedback is now commonly accepted as a technique for shaping brain electrical behavior (2). Thus, it is appropriate to focus attention on how EEG conditioning and feedback techniques might be applied for human-machine interface and control. In fact, recent papers report the use of operantly conditioned brain responses to control physical devices (3,4).

RATIONALE

The direct brain interface described below is based on operant conditioning of the SSVER. This technique should not be confused with approaches based on the interpretation of spontaneous EEG patterns (5,6). The objective of our approach is to train subjects to exercise frequency-specific control of a steady-state EEG response to a visual stimulus. Use of an external evoking stimulus permits synchronous signal processing with a lock-in amplifier which, in turn, improves noise tolerance and decreases the influence of broad-band muscle artifacts.

DESIGN

The approach described here is a biofeedback system that controls the frequency of an evoking stimulus and simultaneously provides the subject with feedback on the magnitude of his or her SSVER response at that frequency. The principal system components are visual stimulus lamps, gold-cup EEG electrodes, a high-gain biological signal amplifier, a lock-in amplifier system, a device control algorithm, and a biofeedback and task display.

Two fluorescent lamps, mounted behind a diffusing screen, are sinusoidally modulated in intensity at 13.25 Hz to evoke a steady-state response in the visual cortex. The signal used for control is the magnitude of the bipolar SSVER recorded over occipital sites O1 and O2 (left and right visual cortical hemispheres, respectively, according to the 10-20 International System for surface electrode placement). The EEG signal from the scalp electrodes is amplified and then synchronously processed by the lock-in amplifier system. The lock-in amplifier provides a continuous measure of the magnitude of the 13.25 Hz SSVER component of the EEG signal. This magnitude information is simultaneously provided to the subject feedback display and to the device control algorithm. The device control algorithm employs "pulsatile" logic which permits stable control of an external device despite variability in the subject's SSVER control. This algorithm requires the subject to hold the SSVER magnitude above or below set thresholds, for a set duration, before a discrete output is generated. This output can be used to control a variety of devices. Typical parameter settings produce an output when the SSVER remains above or below threshold for 75% of the samples in a one-half second interval. These settings require the subject to produce sustained changes in the SSVER; however, brief SSVER fluctuations do not interrupt system control. The threshold, duration and percentage parameters are adjustable for individual subjects and for specific device applications.

The direct brain interface was developed in an Air Force laboratory and we have used it to control the roll motion of a simple flight simulator (Figure 1). By attending to near real-time feedback of the

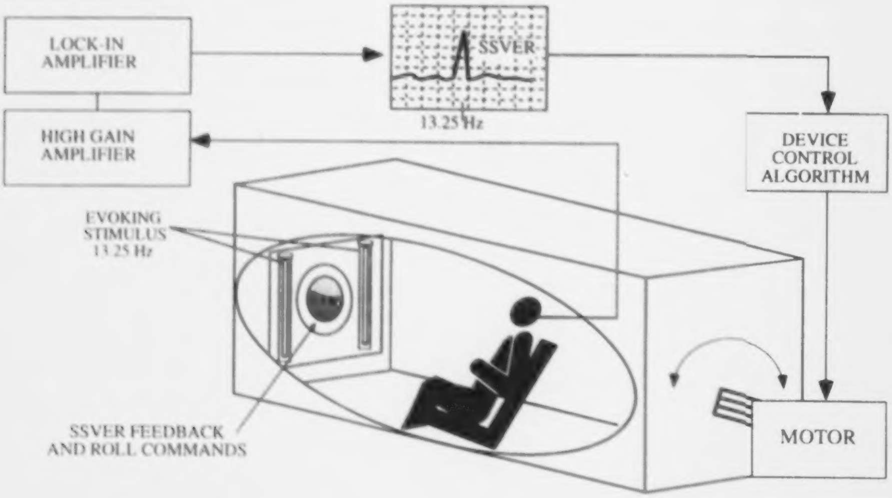


Figure 1. Brain interface control system for flight simulator.

SSVER magnitude, subjects learn to self-regulate their response, which in turn controls the simulator's roll position. As the subject increases SSVER magnitude above one threshold, the feedback display element moves toward the right, and the simulator rolls to the right. When the SSVER magnitude is decreased below a lower threshold value, the feedback element moves to the left, and the simulator rolls to the left. A task display in the simulator provides a random series of commands requiring the subject to roll right or left, to test accuracy of control.

A typical simulator control trial is presented in Figure 2. The subject modulates the SSVER (as measured by the lock-in amplifier) in response to the roll command and the simulator moves in accordance with the output of the direct brain interface. The operation of the pulsatile algorithm can be observed as simulator motion steps, separated by one-half second intervals.

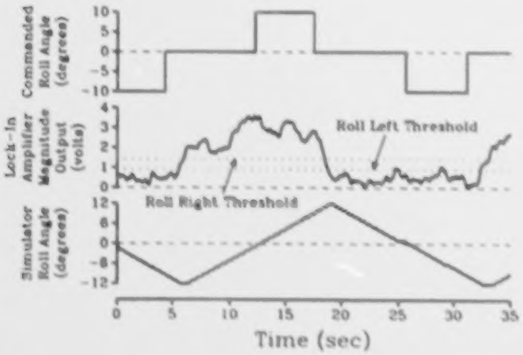


Figure 2. Sample simulator control trial from subject 3 after approximately 12 hours training. Roll right is positive, left is negative.

DEVELOPMENT AND EVALUATION

Earlier research in our laboratory addressed factors pertinent to the development of brain actuated control: stimulus frequency, feedback effectiveness, and feedback modality (7,8). Although artifactual mediation is highly unlikely when a narrow-bandwidth signal and differential recording are utilized, data were collected to rule out the possibility of muscle biopotential contamination of the EEG response. Research is in progress to investigate the neurophysiological basis of SSVER control, as well as to improve brain response measurement, control algorithms, and interface designs for real-world applications. Results to date suggest that subjects modulate bipolar SSVER magnitude primarily by self-regulating inter-hemispheric phase differences (4). Further, SSVER self-regulation may involve neural operations not limited to those traditionally accessed over the occipital scalp (9). Performance evaluations have demonstrated that humans can learn to self-regulate the SSVER with minimal training, and that this ability can be used for device control (Figure 3). Subjects trained in the simulator typically acquire over 80% of the targets presented in test trials. Further, SSVER control of skeletal muscles using functional electrical stimulation is described in a companion paper in these proceedings (10).

BEST COPY AVAILABLE

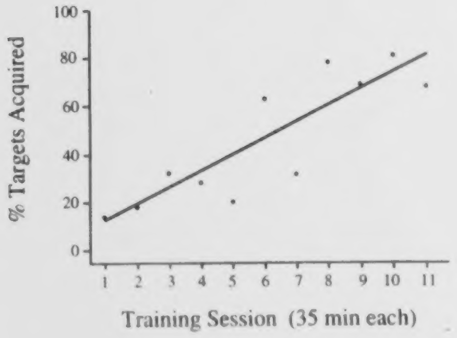


Figure 3. Learning curve for subject 3. Subject had no prior biofeedback or simulator training. Data points are means of 16 trials in each session. Solid line is a linear regression on these means.

DISCUSSION

Despite encouraging results in the laboratory, additional research and development is required before brain actuated control can be used in applied settings. Various evoking stimulus modalities (visual, tactile, etc.) should be compared. In addition, the advantages of evoked and non-evoked brain response approaches (3) should be evaluated. All current brain interface systems are constrained by limited precision, reliability and speed of control. Algorithms are needed to improve the separation of intentional and unintentional EEG changes, permit multi-channel control, automate calibration and improve processing speed. Numerous human factors issues remain largely unexplored; successful application will require optimal allocation of functions to conventional and brain controls. Complex task environments must be studied to determine the effects of concurrent task performance on brain actuated control.

The most likely near-term application of direct brain interfaces is in the field of rehabilitation. People with little or no motor control may, with brain interfaces, learn to control computers, prosthetic limbs, wheelchairs or home systems. Current U.S. Air Force interest is in providing alternative control of secondary cockpit functions (e.g., radio frequency or radar mode selection), especially during maximum workload or high-g flight.

REFERENCES

(1) B. Rockstroh, N. Birbaumer, T. Elbert, and W. Lutzenberger, Operant control of EEG and event-related and slow potentials, *Biofeedback and Self-Regulation*, vol. 9(2), pp. 139-160, 1984.

(2) T. Elbert, B. Rockstroh, W. Lutzenberger, and N. Birbaumer, *Self-Regulation of the Brain and Behavior*, New York: Springer-Verlag, 1984.

(3) J.R. Wolpaw and D.J. McFarland, Multichannel EEG-based brain-computer communication, *Electroenceph. Clinical Neurophysiol.*, vol. 90, pp. 444-449, 1994.

(4) V.T. Nasman, D. Ingle, and J. Schnurer, Differential hemispheric activation as a possible mechanism for SSVER self-regulation, *Psychophysiology*, vol. 31, S71, 1994. (abstract)

(5) L.A. Farwell and E. Donchin, Talking off the top of your head: Toward a mental prothesis utilizing event-related brain potentials, *Electroenceph. Clinical Neurophysiol.*, vol. 70, pp. 510-513, 1988.

(6) E.E. Sutter, The visual evoked response as a communication channel, *IEEE/NSF Symposium on Biosensors*, pp. 95-100, 1984.

(7) J.H. Schnurer, D.F. Ingle, C.W. Downey, and A.M. Junker, A real time frequency analysis methodology for evoked potential loop-closure, *Proceedings of the 1988 NAECON*, vol. 4, pp. 1530-1535, 1988.

(8) A.M. Junker, J.H. Schnurer, D.F. Ingle, and C.W. Downey, Loop-Closure of the Visual-Cortical Response, Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, AAMRL-TR-88-014, 1988.

(9) D. Ingle and V.T. Nasman, Self-regulation of the steady-state visual evoked response as recorded at multiple scalp sites, *Psychophysiology*, vol 31, S58, 1994. (abstract)

(10) G.L. Calhoun, G.R. McMillan, M.S. Middendorf, J.H. Schnurer, D.F. Ingle, R.M. Glaser, and S.F. Figoni, Functional electrical stimulator control with a direct brain interface, *Proc. RESNA 18th Ann. Conf.*, 1995.

ACKNOWLEDGMENTS

The Logicon Technical Services, Inc. and Symvionics, Inc. portions of this effort were performed in support of the USAF Armstrong Laboratory Contract F41624-94-D-6000.

Mailing address: Grant McMillan, Ph.D.
AL/CFHP, Wright-Patterson AFB, OH 45433
Phone: 513-255-8766; Fax: 513-255-8752
E-mail: gmcmillan@falcon.aamrl.wpafb.af.mil

BEST COPY AVAILABLE

CONTROL OF FUNCTIONAL ELECTRICAL STIMULATION WITH A DIRECT BRAIN INTERFACE

Gloria L. Calhoun, Grant R. McMillan, and Paul E. Morton, Armstrong Laboratory, WPAFB, OH
Matthew S. Middendorf, Symvionics, Inc., John H. Schnurer and David F. Ingle, LTSI, Dayton, OH
Roger M. Glaser, Wright State University School of Medicine, Dayton, OH
Stephen F. Figoni, Dayton VA Medical Center, Dayton, OH

ABSTRACT

Rehabilitation engineers continue to search for technology to expand the human-machine interaction capabilities of people with disabilities. A direct brain interface was developed which uses the magnitude of the steady-state visual evoked response (SSVER) as a control signal. Wearing surface electrodes, people learn to modify their SSVER in order to establish control signals. After further development, this technology may allow people with severe physical disabilities to control computers, prosthetic limbs, wheelchairs, or home systems. The potential application of this brain interface was demonstrated in the operation of a functional electrical stimulator; results from this pilot study are described.

BACKGROUND

Most individuals with spinal cord injury (SCI), as well as those with other neuromuscular impairments resulting from upper motor neuron damage, experience lower-limb muscle paralysis. The resulting lower-limb disuse can lead to muscle atrophy and bone demineralization. Functional electrical stimulation (FES) induced exercise has been shown to improve the strength, endurance, size and appearance of muscles with spastic paralysis (1). However, SCI volunteers who participate in FES exercise programs do not have *direct* mental control over the induced movements. At present, methods of control consist of physical and mechanical interactions such as ON/OFF switches or more complicated computer-controlled FES. Although these methods give reliable control over if/when the FES is applied, switch control is indirect and "external" to the individual. The application of a direct brain interface to the operation of FES is an initial attempt to provide more direct voluntary motor control to persons with significant paralysis.

Control of one's environment is an important psychological issue after SCI (2). Paralysis of limb musculature severely limits the ways in which an individual can interact with his or her environment. Self-image and perception of control may be enhanced by regaining a sense of voluntary motor function. Brain actuated control of movement will require motivation and mental effort to begin and continue exercise; brain actuated-FES exercise may thus be more psychologically satisfying than externally-controlled FES. Thus, high subject motivation is expected to be an attractive feature of this alternative form of control. An integration of direct brain interface and FES technologies is needed to realize the potential benefits of this union.

OBJECTIVE

Research results have conclusively demonstrated operant conditioning of electrical brain activity (3); it is now possible to focus attention on control applications. Control of a motion-based flight simulator has been demonstrated with a direct brain interface based on SSVER self-regulation. The design of this brain interface is described in these proceedings (4). The purpose of the present pilot study was to apply the same approach to a rehabilitation device. Specifically, the objective was to demonstrate that reliable control of knee extension can be achieved using a brain interface to control FES.

METHOD

Apparatus: The direct brain interface was a biofeedback system that controls the frequency of an evoking stimulus and provides the subject with feedback on the strength of the SSVER at that stimulus frequency (4).

Two fluorescent lamps modulated in intensity at 13.25 Hz were used to evoke a steady-state response in the visual cortex. The signal used for control was the magnitude of the bipolar SSVER recorded over occipital sites O1 and O2 (left and right visual cortical hemispheres respectively, according to the 10-20 International System for surface electrode placement). The electroencephalographic (EEG) signal from the scalp electrodes was amplified and then processed by a lock-in amplifier system. The lock-in amplifier provided a continuous measure of the magnitude of the 13.25 Hz SSVER component of the EEG signal. This magnitude information was simultaneously provided to the subject feedback display and to the FES control algorithm.

Subjects were required to hold the SSVER magnitude above or below set thresholds for one second before a command was sent to the FES

704

system. Increasing SSVER magnitude above the FES-ON threshold caused the FES to activate at the contraction current threshold level and begin ramping the current upward, gradually recruiting additional muscle fibers to cause knee extension. For safety, when the knee reached the commanded target angle, a computer periodically modulated (duty-cycled) the FES current to prevent the limb from becoming hyper extended. Duty-cycling was maintained until subjects successfully reached the FES-OFF threshold. SSVER magnitude below the lower (FES-OFF) threshold resulted in the reversal of the FES system and the subsequent ramp-down of the current.

Subjects: Three able-bodied subjects were tested; each had previous experience with the brain interface for flight simulator control (4). Subjects wore electrodes at scalp locations O1-O2. Two carbonized rubber electrodes were affixed to the anterior surface of the thigh over the rectus femoris muscle to provide stimulation from a FES system (5). Subjects also wore a goniometer to measure knee angle for continuous monitoring of performance and for feedback.

Task: The experimental task required extension of the right knee to the commanded target angle (15, 30, or 45 degrees, measured from the lower limb perpendicular to the floor; 90 degrees knee flexion). Subjects viewed a computer monitor which provided near real-time feedback of the SSVER magnitude, FES milliamperage level, target angle, and actual knee angle. Presentation of the next target angle was contingent on the reduction of current level to 0 mA and knee angle to 0 degrees. By attending to the feedback, subjects learned to control SSVER magnitude and, in turn, the "ramp- up/down" status of the FES and resultant limb position. For each target, SSVER magnitude, FES milliamperage level, target angle and actual knee angle were recorded as a function of time.

RESULTS

Each of the three subjects participated in three to five test sessions (3 to 5 training hours). In each case, the session that represented best performance was selected for analysis. Each subject's data were examined separately; any SSVER latencies greater than 3 standard deviations from the individual subject's mean SSVER latency were discarded. The resulting data base consisted of 56 FES-ON latencies and 54 FES-OFF latencies. Trial data were also examined to ensure that there was a corresponding change in FES current level with each change in knee angle. This procedure confirmed that the able-bodied subjects accomplished knee extension by controlling the brain-FES interface.

Figure 1 shows target angle, SSVER magnitude, FES current, and knee angle as a function of time in a sample trial. All three subjects were highly successful in repositioning the lower limb to match the target knee angle (95.8% of the targets were acquired) and in returning the limb to its resting position. It took an average of 4.28 seconds after target presentation for subjects to meet the FES-ON threshold and initiate current ramp-up. After target acquisition, subjects took an average of 5.93 seconds to meet the FES-OFF threshold and initiate current ramp-down. Note that the delay inherent in the system was approximately 2.5 seconds due to low-pass filtering and control algorithm parameters (i.e., requiring the SSVER magnitude to satisfy threshold for one second). Subjects' latencies were variable (standard deviations of FES-ON and -OFF times were 1.91 and 1.41 seconds, respectively), which may reflect the difficulty of concentrating on neural self-regulation while experiencing the discomfort associated with neuromuscular electrical stimulation.

DISCUSSION

For people with little or no ability to control motor functions, a direct brain interface may provide a powerful link between mind and machine. The concept of using a brain interface for rehabilitation may have originated in 1964 with Dewan (6), who suggested that the ability to "manipulate a switch simply by altering thoughts in some way" could be applied to the field of prosthetics. The results of this pilot study demonstrate that a brain interface based on SSVER self-regulation can be used to control FES operation. The high percentage of targets successfully acquired indicates that able-bodied subjects can be trained in brain actuated control of FES, despite the possible discomfort produced by the stimulation. Furthermore, it is anticipated that significant improvements in latency can be achieved with additional system refinement and development and that this type of brain interface has the potential to be an efficient controller of paralyzed muscles. The technology transfer of a brain interface may enhance the rehabilitative outcome of individuals with SCIs by providing them with direct voluntary control over the exercise of paralyzed muscles. Potential advantages include increased motivation to exercise, improved psychological status, and a more natural sense of control and muscle activation. Future applications may include the control of switches on wheelchairs, computers, robotic arms, and environmental/home systems.

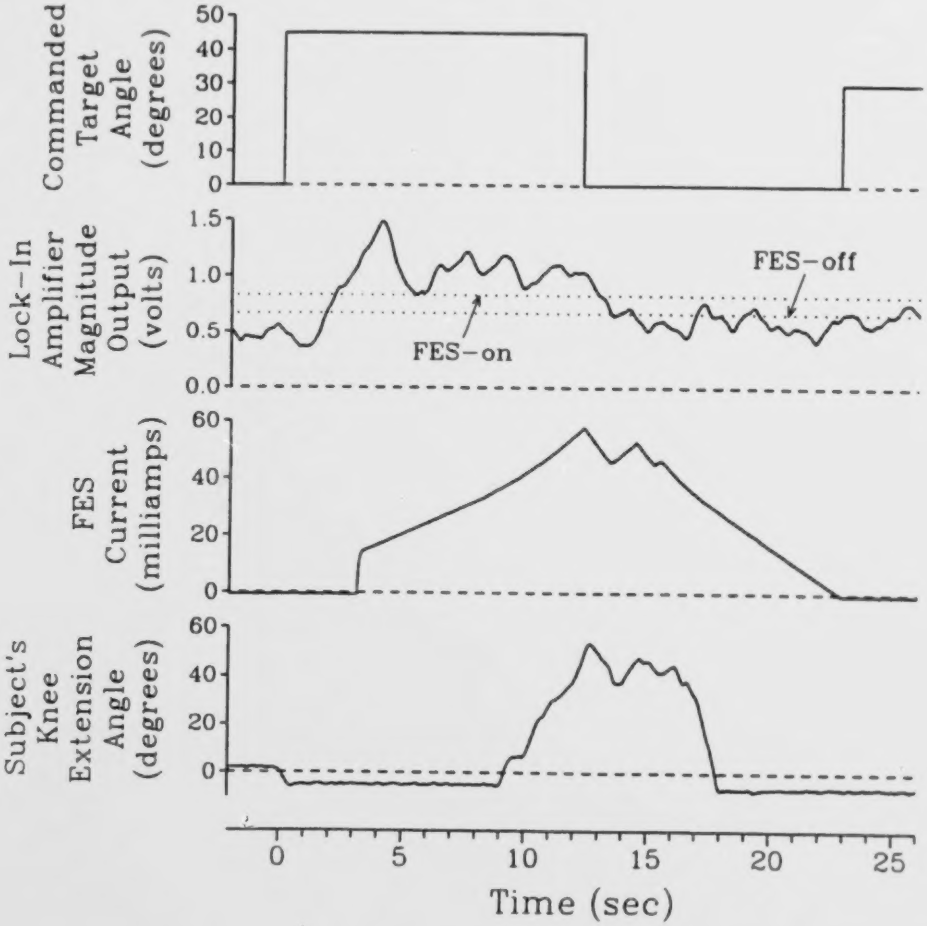


Figure 1. Sample trial of brain interface control of FES-induced knee extension exercise in an able-bodied subject (#11). The lock-in amplifier output is a measure of SSVER magnitude.

REFERENCES

(1) P.D. Faghri, R.M. Glaser, S.F. Figoni, D.S. Miles, S.C. Gupta, Feasibility of using two FNS exercise modes for spinal cord injured patients, *Clin. Kinesiol.* 43:62-68, 1989.

(2) R.G. Frank and T.R. Elliott, Spinal cord injury and health locus of control beliefs. *Paraplegia* 27:250-256, 1989.

(3) T. Elbert, B. Rockstroh, W. Lutzenberger, and N. Birbaumer, *Self-Regulation of the Brain and Behavior*, New York: Springer-Verlag, 1984.

(4) G.R. McMillan, G.L. Calhoun, M.S. Middendorf, D.F. Ingle, J.H. Schnurer, V.T. Nasman, Direct brain interface utilizing self regulation of steady-state visual evoked response, *Proc. RESNA 18th Ann. Conf.*, 1995.

(5) R.M. Glaser, S.R. Collins, and H.R. Horgun, An electrical stimulator for functional neuromuscular stimulation exercise, *Proc. RESNA 10th Ann. Conf.*, pp. 597-599, 1987.

(6) E.M. Dewan, Communication by Electroencephalography, Air Force Cambridge Research Laboratories, AFCRL-64-910, Special Reports 12, 1964.

ACKNOWLEDGMENTS

The LTSI and Symvionics portions of this effort were performed in support of the USAF Armstrong Laboratory, Contract F41624-94-D6000.

Mailing address: Gloria Calhoun
AL/CFHP Wright-Patterson AFB, OH 45433
Phone: 513-255-3856; Fax: 513-255-8752
E-mail: gcalhoun@falcon.aamrl.wpafb.af.mil

USING THE ELECTROOCULOGRAM AS A MEANS FOR COMPUTER CONTROL

R. Benjamin Knapp Ph.D.
Electrical Engineering Department, San Jose State University
Hugh Lusted Ph.D.
BioControl Systems, Palo Alto California
David W. Patmore
Computer Engineering Department, University of California, Santa Cruz

ABSTRACT

The physiological signal known as the electrooculogram (EOG), can be used to move the cursor on a computer to where the eye is pointing. This enables computer use by people who, due to physical disabilities, have been unable to operate standard interface devices such as a keyboard or a mouse. While the EOG is a fast and inexpensive technique for measuring eye gaze, its accuracy is limited due to long term signal drift. To reduce the inherent signal drift, real-time fuzzy pattern recognition is implemented on the BioMuse system. The effect of this pattern recognition on EOG accuracy is presented. In addition the results from a study of pointing accuracy of this system are presented.

BACKGROUND

Individuals who are physically disabled can often use computers to augment their own abilities to interact with the environment. In extreme situations, eye movement may be one of only a few channels of communication available. Consequently, it is believed that a well designed eye pointing system can be an ideal tool for assisting physically disabled individuals to use a computer easily and reliably. There are many eye movement recording systems available, each with their own advantages and disadvantages. Of these systems, the development of an eye pointing system based on the electrooculogram eye movement recording technique was chosen in the belief that it has the most advantages and highest probability of success as a fast, reliable means for a physically disabled person to use a computer.

The electrooculogram is derived from the resting potential, known as the Corneal-Retinal Potential (CRP), generated in the eyeball by the metabolically active retinal epithelium. With the appropriate recording electrode placement, the CRP can be used as an indicator of eye movement since the amplitude of this potential can be observed to vary proportionally with eye displacement over a range of about 30 degrees from center. Over the past ten years, various investigators have begun to use the EOG to measure the absolute position of the eye relative to the head in order to control a computer (1)(2)(4). There are several advantages of the EOG over the other four commonly used eye tracking techniques It is relatively low cost. It does not obstruct the field of view. As long as the ambient light is reasonably constant, it works well for low or high illumination levels. It does not require rigid head stabilization or precise head alignment with the computer screen since the eye position relative to the head is what is being measured and there are no cameras to be obstructed by a slightly turned head. A one time calibration for head position is all that is necessary. It also does not require expensive video imaging techniques. Finally the headband can be worn all day so that an attendant only has to help the disabled individual put on the headband once a day.

THE PROBLEM

The primary problem with using EOG is that an eye controller with long term accuracy to a few degrees of arc (which is necessary to create a reliable mouse replacement) has not been created. This is caused by recording artifacts referred to as drift. Drift is the long term change in the EOG recording not caused by eye motion. It causes the computer estimate of eye gaze location to shift away from the subject's actual eye gaze location. There are four significant causes of drift: variation of the potential of the electrode skin interface, motion artifact of the recording electrodes, changes in skin chemistry (specifically the GSR), and slow variation of the CRP. These effects are read as noise mixed with the true DC information. The chief difficulty for eye tracking is to separate the noise from the data. In order to maintain a fast tracking rate of less than a quarter of a second, special signal processing is done. The tradeoff is between the system having the ability to track the eyes quickly when the user flicks them from one screen location to another and having the system track noise when the eyes are not in motion. Tracking noise is a problem because the system's eye gaze estimation varies from the correct position.

SOLUTION TO THE PROBLEM

The authors have developed a fuzzy rule base to use features of the EOG such as velocity, acceleration, and change in direction to separate true eye movement (specifically saccadic eye movement) from drift. Fundamentally, however, drift can behave in many ways like eye movement. To overcome this the authors presently use the EOG from both eyes since the drift from the individual eye's EOG is not entirely correlated (3) (motion artifact and skin chemistry changes are correlated, electrode-skin potential is less so). Thus the features of each individual eye's movement are all presented simultaneously to the fuzzy pattern recognition system. This system then decides what fraction of the change in the EOG signal is actual eye movement and not drift.

EVALUATION METHODS

System Configuration

The present system developed and used by the authors uses a four channel (horizontal and vertical channels for each eye) EOG signal acquisition headband. The headband contains a 5 electrode montage to measure the horizontal eye movement and two side arms that position an electrode under each eye to measure the vertical eye movement.

The electrodes are a key element in the EOG signal acquisition system. The authors have developed special purpose electrodes which have very low drift and offset characteristics. The electrodes consist of a three layer construction: foam backing/snap connector, silver chloride electrode element, and hydrogel layer. The gel creates an ionic bridge between the skin and the electrode element and has been specifically designed to reduce ion migration, thus reducing one component of signal drift.

The headband is attached to the BioMuse real-time signal processing system. The BioMuse was designed by the authors to acquire up to eight channels of physiological signals simultaneously, perform real-time signal analysis and output the processed signal directly to a personal computer.

Testing the Pattern Recognition Algorithm

To test the ability of the fuzzy pattern recognition software, EOG data was collected from subjects who were asked to look at several points on a computer screen. In the results presented below the subject was asked to look at the center of the screen, then counter clockwise at the four corners of the screen starting with and returning to the upper left corner and then finally back to the center. This data was processed off-line and then used to determine the points at which the subject gazed. A goodness of fit number was then maximized by modifying the pattern recognition algorithm.

Testing the Eye Controller

To determine the performance of the EOG based eye controller in a real-time environment, a study was performed on six subjects over three trials to test both accuracy and speed. Graphical screens and automatic scoring software were designed specifically for this study. In the basic testing configuration two different screens are displayed to test the eye controlling capabilities of the subject.

The first screen is a 3X4 array of squares numbered 1 through 12, and the second screen is a 2X3 array of numbers numbered 1 through 6. A small blue target box highlights the number at the center of the square, indicating the location to which the subject is to direct his or her gaze. The cursor is a small round icon which is moved by the subject's eye movements. When the cursor is placed in the square with the blue target indicator for more than 0.5 sec., the test program records a hit.

The test software is designed to evoke a selection of different eye movements from the test subjects. Thus, the movement of the blue target indicator leads the subject through various eye movements between the squares. Within a test session subjects are required to make vertical, horizontal, and diagonal eye movements of both short (square to square) and long (across the screen) distances.

Two different testing protocols were designed to evaluate different aspects of the eye controller system. The two protocols are term "timed" and "accuracy". The timed protocol presents the blue target indicator to the subject, and the subject is instructed to place the cursor into the indicated square, and the time to make the direct hit is recorded in seconds. The accuracy mode presents the blue indicator to the subject, and the first eye movement toward the indicated square is recorded. Thus, for the accuracy mode, the initial saccadic eye movement is scored according to the actual location of the cursor in relation to the indicated square.

Before each testing session, the subject is calibrated on the eye controller system. This means the values such as signal gain, signal to pixel mapping, and fuzzy membership functions are all determined. A "goodness of calibration" number was determined for all four EOG channels (left and right, horizontal and vertical) based on the magnitude and variance of the signal drift. The calibration results are an important factor in the usability of the eye controller, since a good calibration places the cursor optimally in the subject's point of gaze fixation.

RESULTS

Testing the Pattern Recognition Algorithm

Figure #1 shows the unprocessed EOG data from one subject using the protocol described previously.

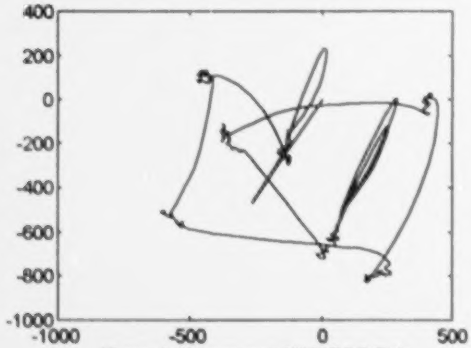


Figure 1: Unprocessed X-Y EOG Data

Note that the horizontal and vertical eye motion are actually recorded as sloped movements. This is the effect of the signal drift. The rapid vertical motions are blinks.

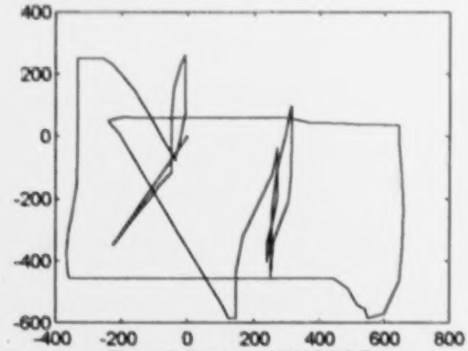


Figure 2: Processed X-Y EOG Data

Figure #2 shows the EOG data after it has been processed using fuzzy pattern recognition. The horizontal and vertical eye motions are now displayed correctly. The starting and stopping points are not the same due to the distortion caused by the eye blinks. This is easily removed by suspending the eye tracking during the blink.

Testing the Eye Controller

For the timed protocol, on the 3X4 square screen, the average time to select the correct square was 1.8 +/- 0.9 sec. On the 2X3 screen the average time to select the correct square was 0.6 +/- 0.6 sec. Most of the response times for both screens were considerably less than the average - typically around 0.25 sec. Using the current fuzzy pattern recognition algorithm, it was quite difficult for the subject to move the cursor to boxes in the center portion of the screen. Thus it could take the subject as long as 10 sec to move the cursor to these positions.

For the accuracy protocol, on the 3X4 square screen, the average accuracy was 51.6 +/- 18 %. On the 2X3 screen, the average accuracy was 75.1 +/- 14.6 %. It should be noted in the accuracy protocol that for the 3X4 grid the average distance from the correct box for a "miss" is 1.2 and for the 2X3 grid is nearly 1. Thus, when a mistake was made, it was rarely more than one box off. Also, as mentioned previously, only the initial gaze position was recorded. No "looking around" was allowed.

DISCUSSION

The use of fuzzy pattern recognition to separate eye motion from signal drift on an EOG eye controller is quite promising. While the non-real-time testing of the algorithm is quite successful, there is still a problem when using the system as a real-time cursor controller. There was a large correlation between the "goodness of calibration" and the results of both subject testing protocols. This underscores the extremely detrimental effect that drift still has on an EOG based eye controller. With high signal drift, the pattern recognition algorithm will sometimes not recognize small, slow eye movements of the kind needed to traverse the center of the computer screen. To over come this the author is now improving the pattern recognition software to include long term LPC based features to further distinguish saccadic eye movements from drift and the initial results are encouraging.

REFERENCES

1. Asche, D., Cook, A., and Van Ness, H. *A Three Electrode EOG for Use as a Communication Interface for the Nonvocal, Physically Handicapped.* Proc. Ann. Conf. Eng., Med., & Biol., v18, p2, 1976.

2. Knapp, R.B. and H. Lusted. *BioContollers for the Physically Disabled: A Direct Link from Nervous System to Computer.* Proc. 6th Ann. Conf. on Tech. & Pers. with Disab., Los Angeles, CA, March 1992.

3. Knapp, R.B., Hake, L.E., and Lusted, H.S. *Method and Apparatus for Eye Tracking for Convergence and Strabismus Measurement.* United States Patent #5,293,187, March 1994.

4. LaCourse, J.R. and F.C.J. Hludik, *An Eye Movement Communication-Control System for the Disabled.* IEEE Trans. on Bio. Eng., 1990. **37**(12): p.1215-1220.

R. Benjamin Knapp, PhD, Dept. of Electrical Engineering, San Jose State University San Jose, CA 95192-0084

Ph: (408) 924-3960 Fax: (408) 924-3925

e-mail: ben@ccrma.stanford.edu

A CURSOR CONTROLLER USING EVOKED POTENTIALS AND EOG

David W. Patmore
Computer Engineering Department, University of California, Santa Cruz
R. Benjamin Knapp Ph.D.
Electrical Engineering Department, San Jose State University

ABSTRACT

Individuals with disabilities need channels other than ordinary keyboard typing for control of computers. The use of eye gaze has good potential for communication augmentation. Several different methods exist for detecting the direction of eye gaze, one of which does not require exact head positioning or visually obstructive measurements. This method uses the electrooculogram (EOG), which is fast, but suffers from long term signal drift. This paper presents a method that uses visually evoked response potentials (VERP) to create a feedback loop which overcomes this drift problem. The VERP/EOG controller design takes advantage of the speed of the EOG reponse and the long term accuracy of the VERP. The design of the VERP feedback loop along with data from its development is discussed.

BACKGROUND

Many different computer controllers exist to allow physically disabled individuals to communicate. As the level of disability approaches the locked-in state, the options available to the user become fewer. Eye gaze is one control option that is used by such individuals (1)(2).

Modern systems often use a computer display to present choices. The user looks at a target selection on the display, and, via different methods, the gaze-target is detected and the desired action followed by the computer. A drawback to this approach is that the user is limited to specially designed software.

Several researchers have developed eye gaze controllers using EOG(1)(3). The EOG controller moves the cursor to the gaze-target, which, unlike the grid paradigm, provides the user with the freedom to operate any graphical interface. EOG is the measurement of the Corneal Retinal Potential (CRP) using surface electrodes placed around the eyes of the user. The CRP varies linearly with eye movement along both horizontal and vertical axes within 30 degrees of the forward position(4). EOG systems have very fast response (less than .25 sec delay), but, due to distortion caused by signal drift, can become uncalibrated very quickly.

The system developed by the authors measures the EOG using electrodes mounted in a special headband that can be attached to a user by untrained personnel. The VERP/EOG controller removes the drift problem by feeding back the location of eye gaze as measured with an evoked response signal. The system is designed to maintain the ease and comfort of attachment of the original EOG headband and is shown in figure 1.

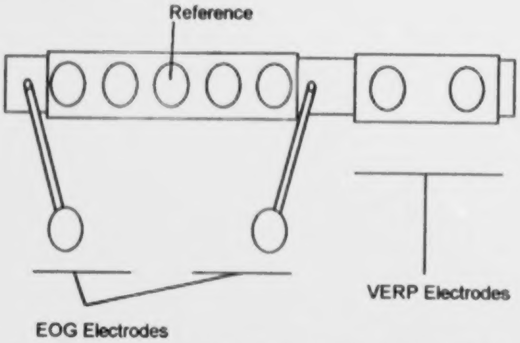


Figure 1: HEADBAND USED FOR SIGNAL ACQUISITION

The first VERP-based interface was developed by Sutter(2). The VERP is the brain's response to a flash of light, usually measured from the occipital cortex. In Sutter's interface, a computer screen is divided into a grid. A grid element represents a choice that the user may wish to indicate. Each grid element is flashed in a manner distinct from all the other elements, creating a unique VERP pattern for each choice. The key to this system is that the magnitude of the VERP is very sensitive to the stimulus' distance from the center of vision. More than a degree or two from the center of vision, the response falls away quickly.

The weaknesses of the VERP system are its slow response, its dependence on the grid paradigm and the degree of electrode site preparation required. Evoked responses are small relative to the background EEG, and consequently, a stimulus needs to be repeated many times before the magnitude of the response can be measured with confidence. Sutter reports that this system, at best, has an average selection rate of 1.2 seconds. The selection rate is much slower than an eye movement, which can be as fast as 700 degrees/second (5). Good results were obtained through extensive electrode site preparation -- the extreme of which was electrode implantation.

HYPOTHESIS

The fast response of the EOG device may be combined with the calibrating effect of the VERP measurement to create a new feedback circuit. This new circuit will overcome the drift problem of the original EOG device. Figure 2 shows the feedback structure. Two questions must be answered in the development of this system: While maintaining a high level of user comfort, what is the minimal electrode site preparation sufficient to record the feedback signal? Is there an optimal frequency for the VERP stimulus that maximizes its dynamic range in the feedback loop?

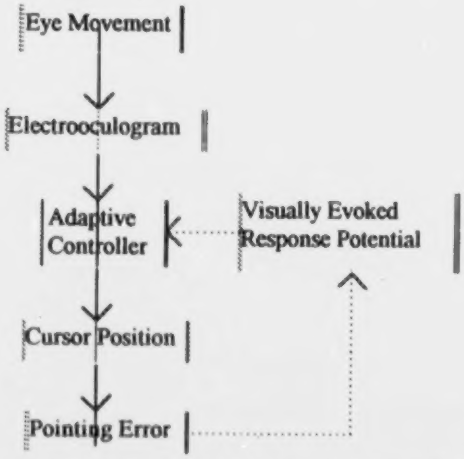


Figure 2: ILLUSTRATION OF CONTROL CIRCUIT

METHOD

Bioelectrical data collection and pattern recognition are performed by a real-time digital signal processor (DSP) system linked to a host computer (PC). The DSP system communicates with the host computer via a serial port, and software on the host interprets the processed data, creating commands for moving the cursor in Microsoft Windows. The host computer also generates a stimulus by flashing the cursor.

The initial development of the system was done using a high-intensity LED as an independent stimulus. The LED, attached to a digital function generator, allowed the stimulus frequency to be precicely tuned. Gel electrodes were used to record EEG since the intention is to develop an inexpensive, easy to apply system.

Data was recorded from each subject over several sessions on different days. Each session was made up of a series of trials, each lasting 16 seconds. During the recording, the subjects were instructed to open and close their eyes at four second intervals. This ensured that there would be no eye blinks during the "eyes open" intervals.

Electrode placement was either over the frontal or occipital lobe; in both cases, the center of the forehead was used as the reference. The stimulus frequency was varied by 1/2 Hz steps between 3Hz and 21Hz leaving a gap between 8Hz and 14Hz to avoid interference from alpha waves. Trials with no stimulus from the LED were also recorded.

RESULTS

Figure 3 shows the variation of the evoked response with frequency.

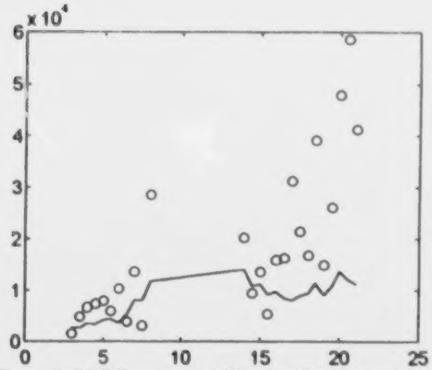


Figure 3: EEG Response at Stimulus Frequency (sub. A)

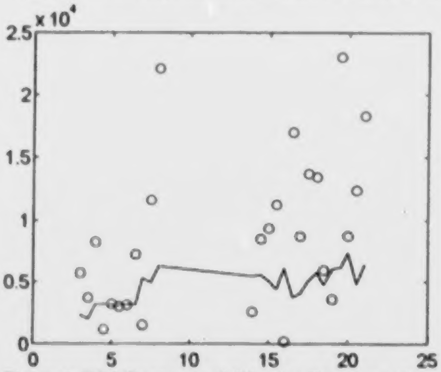


Figure 4: EEG Response at Stimulus Frequency (sub. B)

The frequency response was determined by performing a Fourier Transform on the eight seconds of "eyes open" data. Each circle shows the magnitude of the VERP at the corresponding frequency of stimulation. The continuous line is made by averaging the responses of all the trials and then subtracting the circled value. This graph shows how some stimulus frequencies have responses that are distinct from background EEG. Figure 4 shows the same plot, using data from a different subject

Figure 5 shows the 20 Hz component of the VERP as stimulated by all the tested frequencies. In effect, this is an "exploded view" of the 20 Hz column of figure 3. In this figure, "o" indicates the trial with a 20Hz stimulus.

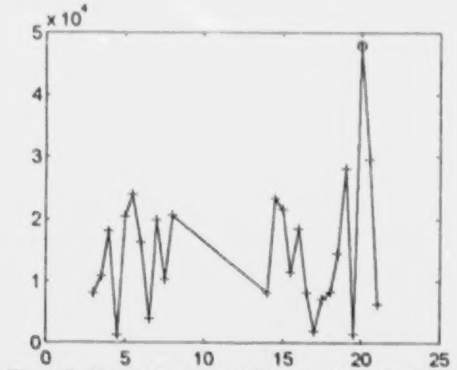


Figure 5: Narrowband EEG (20 Hz) vs Stimulus Frequenc

Figure 6 shows the same data of figure 5 using a shorter analysis window. The data is averaged in 0.2 sec frames over a 1 second interval. A Fourier Transform of the frame average is then computed. The "o" again indicates the trial with a 20Hz stimulus.

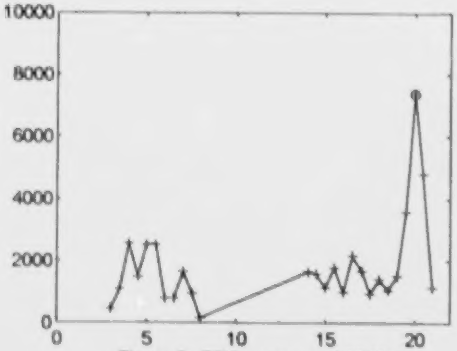


Figure 6: EEG response at 20 Hz

DISCUSSION

Figures 3 and 4 show that both subject A and B had significant peaks of stimulus response, both at around 3Hz and 20Hz stimulus rates. Subject discomfort was high with the low frequency stimulus, while at the higher rate, the flashing effect was less disturbing. At the higher stimulus rate, each subject had a different "best" stimulus frequency; Subject A responded to a 20Hz flash, and subject B responded to a 21Hz flash most strongly. The difference in response between the two subjects suggests that a system with tunable stimulus frequency is necessary.

The graph in figure 5 shows that the evoked response from a 20Hz stimulus (subject A) is clearly larger than the background EEG that appears in the 20Hz band. Figure 6 shows that only one second of data is needed to determine the presence of the VERP. This speed is fast enough to provide the EOG controller with the ability to lock in on the point of eye-fixation.

All of the data indicates that even with a less exacting electrode preparation, the VERP magnitude can be estimated. Future work will explore enhancement methods such as Davila's (6) for estimating the magnitude of periodic visual evoked responses in order to further reduce the response time of the VERP system.

REFERENCES

1. Knapp, R.B. and H. Lusted. *Biological Signal Processing in Virtual Reality Applications*. in *Virtual Reality and Persons with Disabilities*. 1993. San Francisco, CA:

2. Sutter, E.E., *The brain response interface: communication through visually-induced electrical brain responses*. Journal of Microcomputer Applications, 1992. **15**: p. 31-45.

3. LaCourse, J.R. and F.C.J. Hludik, *An Eye Movement Communication-Control System for the Disabled*. IEEE Transactions on Biomedical Engineering, 1990. **37**(12): p. 1215-1220.

4. Webster, J.G., ed. *Medical Instrumentation Application and Design*. 2 ed. 1992, Houghton Mifflin Company: Boston.

5. Pedersen, R.A., L.A. Abel, and B.T. Troost, *Eye Movements*, in *BioMedical Foundations of Opthalmology*.

6. Davila, C.E., A. Abaye, and A. Khotanzad, *Estimation of Single Sweep Steady-State Visual Evoked Potentials by Adaptive Line Enhancement*. IEEE Trans. on Bio. Eng., 1994. **41**(2): p. 197-200.

ACKNOWLEDGEMENTS

This research is supported by BioControl Systems.

David Patmore
BioControl Systems, Inc.
2555 Park Boulevard,Palo Alto, CA 94306
email: patmore@ce.ucsc.edu

Whitaker Student Scientific Paper Competition

1995 RESNA/Whitaker Student Scientific Paper Competition

The purpose of the RESNA/Whitaker Student Scientific Paper Competition and Awards is to encourage and promote student participation in high quality research related to the fields of rehabilitation engineering and assistive technology. The competition is intended to encourage students from a variety of disciplines to address issues in the field of assistive technology and submit papers for presentation at the annual RESNA conference. This competition is based on scientific merit of the reported research and is structured to be distinct from and complimentary to the student design competition. These awards are supported through the generosity of the Whitaker Foundation.

In this second year of the Student Scientific Paper Competition there were 28 papers submitted. More than three quarters of these papers were deemed meritorious. On the following pages you will find the five award winning papers for the competition this year. (Note that the student awardee is the first author on these papers.) These winning papers were all presented in a special session at the RESNA '95 Conference. This session was unique in that it provided a forum which brought together papers on diverse topics with a focus of high quality research and student involvement.

Because of the high number of exceptional papers this year, an additional award category of honorable mention was added. The following four papers were awarded honorable mention and can be found in their respective SIG sessions in the proceedings:

MJ Foster, DJ McFarland, JR Wolpaw: "Improvement in EEG-Based Brain-Computer Communication by Use of Additional Recording Locations"

RT Laurer, KL Kilgore, PH Peckham: "Control of the Hand Intrinsic Muscles by Functional Electrical Stimulation"

DW Patmore: "A Cursor Controller Using Evoked Potentials and EOG"

DP VanSickle, RA Cooper, RN Robertson: "Smartwheel: Development of a Digital Force and Moment Sensing Pushrim"

I would like to sincerely thank the review committee for this year's competition: Martin Ferguson-Pell PhD, Donald McNeal PhD, Michael Rosen PhD, Mark Strauss PhD, and Machiel Van der Loos PhD. The five winning papers were chosen based on average scores from the five reviewers. Very careful consideration was given to avoid any potential conflicts of interest by (1) blinding the reviewers to the authors and their institutional affiliations (to the best of our abilities), and (2) choosing reviewers who had no association with any of the authors or papers.

It was very gratifying to see an increased number of papers (most of which we would have liked to award) for this year's competition. I hope this trend will continue in future years. I believe that our accomplishments over these first two years demonstrate that we are meeting the goals for the RESNA/Whitaker Student Scientific Paper Competition which include promotion of student participation in assistive technology research and RESNA, improved quality of scientific and engineering research in our field, and enhancement of the scientific forum within RESNA. I hope that we can continue in this fashion for many years to come.

RESNA wishes to thank the Whitaker Foundation for its support, the judging committee for a difficult job well done, and all the students who submitted papers. I invite students to start planning their papers for submission to the 1996 RESNA/Whitaker Student Scientific Paper Competition.

Simon P. Levine, Ph.D.
Chair, RESNA/Whitaker Student Scientific Paper Competition

A NEW APPROACH TO SUPPRESSING ABNORMAL TREMOR THROUGH SIGNAL EQUALIZATION

Juan G. Gonzalez, Edwin A. Heredia, Tariq Rahman, Kenneth E. Barner, Samit K. Basu and Gonzalo R. Arce
Applied Science and Engineering Laboratories
A. I. duPont Institute / University of Delaware
Wilmington, DE U. S. A.

Abstract

In this paper we propose a new approach to tremor suppression using optimally designed digital equalizers derived from pursuit tracking task experiments. First we introduce a performance indicator (F-MSE_d) which is more consistent with the features of the problem than other previously known performance criteria. We then use this indicator to develop a method for the design of tremor-suppression equalizers. The optimal solution is the result of a constrained Wiener equation combined with impulse-shaping of the filter coefficients (pulled-optimization). Pursuit tracking tasks performed with devices that simulate tremor are used to show experimentally the validity of our theoretical concepts. Finally, the potential and enhanced performance of this kind of equalizers is definitively demonstrated through a writing test.

Introduction

The number of people affected by pathological tremor is significant (more than 0.25% in the U.S.). In many cases tremor intensity can be very large, causing total disability to the affected person. Physical and drug therapies have not been very successful in tremor treatment, giving raise to the need for alternative approaches to the problem of tremor suppression.

Important results have been obtained in reducing hand tremor by applying resistive forces to customized joysticks [4] and orthosis [1]. Activities such as driving a wheelchair, manipulating a rehabilitation robot or accessing a computer require that an input device (normally a joystick) generate an intermediate signal which is sent to the controlled subsystem (wheelchair, robot arm or cursor). In addition to resistive force techniques the signal can be digitally filtered before reaching the controlled device.

Some wheelchair controllers introduce low-pass filters to improve the steering accuracy of users with tremor. Riley and Rosen [5] have shown that low-pass filters can sometimes improve tracking performance. However, they also show that depending on the cutoff frequency and the specific subject, low-pass filters can degrade or have no effect in performance. Their final conclusion claims the need for subject-customized filter design.

There is not an *a priori* reason why the best filter has to be low-pass. This paper proposes a general design method for a tremor suppressing filter customizable for any given subject. The ideas developed are novel and derived from the channel equalization problem found in Communications. The discussion here is limited to finite impulse response (FIR) linear filters with applications to two-dimensional movements.

The Equalization Problem

The person and the input device can be considered together as a single two-dimensional channel. The input to this channel is the person's desired movement in the x and y directions. The output is the real movement which is in general a distorted version of the input. For a person with tremor disability the distortion can be significant. The function of an equalizer is to get rid of the distortion and recover the desired signal as efficiently as possible (See Fig. 1).

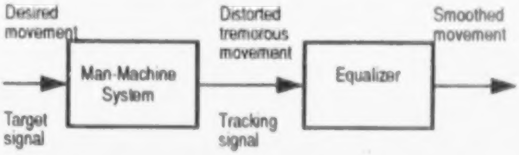


Fig 1. Elements of the equalized man-machine system proposed.

Equalizer Design Tool: The Pursuit Tracking Task

While in Communications a known signal is transmitted to *train* the equalizer, here we train it with a continuous two-dimensional pursuit tracking task in which the target plays the role of the desired signal.

For the project, a computer utility was developed and a Per-force^{TM} robot was adapted to work as a joystick with two degrees of freedom in the horizontal plane. Robot control, task screening, filter design and task evaluation were all performed by the same computer.

Off-line Vs. Adaptive Design

Contrary to a Communication system, the off-line and the adaptively designed equalizers for a man-machine system can be significantly different. The off-line equalizer is designed as the FIR linear filter which maximizes the off-line performance of the pursuit tracking task. That is, *after* the tracking task is done, the equalizer takes the tracking signal and filters it to produce an off-line smoothed signal which the person never sees.

For the adaptive equalizer, filter design is done on-line and the person experiences feedback by seeing the equalized movement on the screen. For the case of consistent convergence, the adaptive option is better because it takes into account the system feedback as well as human system changes. This paper addresses only the issue of the suboptimal solution given by the off-line equalizer.

Performance Criterion

There is no general consensus about what is the most appropriate performance indicator for a pursuit tracking task. Standard measures of the tracking error such as the Mean-Squared Error (MSE) or the Mean-Absolute Error (MAE) are severely affected by tracking delays. Delays are, however, an inherent characteristic of pursuit tracking tasks, and they are not necessarily indicators of poor performance. A tremor suppression system introduces, in general, an additional tracking delay which could increase the tracking error while being effective in eliminating tremor. Thus, plain MSE or similar indicators are not good choices.

Some performance indicators try to overcome the delay effect by considering any tracking component which is linearly-coherent with the target as a normal result of the pursuit tracking task, and attributing the task error to the noncoherent components. In this way, a constant delay can be seen as produced by a linear transformation in the target, and then it does not have incidence in the performance indicator. The information transmission indicator derived from the quasi-linear model [6] and the performance indicator used by the MIT tremor group [1,5] lie into this category.

Although the constant delay problem is solved with this approach, it still has serious problems with its basic assumptions. The tracking coherent component could be a signal very different from the target and induce considerable performance degradation. On the other hand, there could be noncoherent components induced by inherent nonlinear characteristics of the pursuit tracking task which do not significantly degrade the performance.

A more appropriate performance indicator is proposed here (See Fig. 2). Tracking delay is corrected according to an adaptive delay estimation algorithm similar to that developed in [2]. Then, the delay-corrected tracking error is computed by substracting the aligned tracking signal from the target. A linear time invariant filter called the *Performance Filter* enhances the frequencies of more interest.

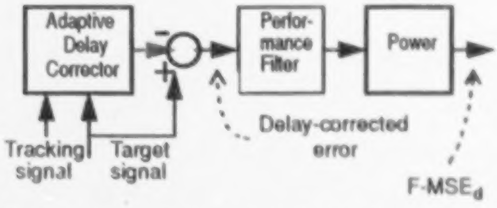


Fig. 2. Sequence of operations required for the proposed performance indicator F-MSE$_d$. Smaller values of F-MSE$_d$ indicate better performance.

The mean-squared value of the filter output is called the *F-MSE$_d$* (Filtered Mean-Squared Value with delay correction). For this study a differentiator has been used as the performance filter. This filter has a twofold advantage: First, tremor suppression is more likely to be achieved if the MSE of the velocity is minimized instead of the MSE of the position. Second, differentiation improves substantially the condition of the tracking autocorrelation matrix which means that the algorithm for equalizer design gives more reliable and stable solutions.

Equalizer Design

Two independent stationary random signals are used as targets for each direction x and y. These signals must be rich in frequency content (to give a more robust equalizer) and at the same time slow enough to allow tracking. The targets used for this study were generated from discrete white gaussian noise passed through a Butterworth low pass filter of order 8 and frequency cutoff 0.5 Hz.

The equalizer for each direction is a digital FIR filter. At time n the smoothed signal s(n) is a linear combination of the previous M coordinates of the tracking

$$s(n) \quad = \mathbf{w}^T \mathbf{r}(n) \tag{1}$$

where $\mathbf{w}=[w_0,\ldots,w_{M-1}]^T$ and $\mathbf{r}(n)=[r(n),\ldots,r(n-M+1)]^T$ are the vector representations of the equalizer impulse response and the tracking signal respectively. The equalizer design consists in finding the vector **w** that minimizes the F-MSE$_d$

$$\text{F-MSE}_d(\mathbf{w})= E\,\{[\,t(n-D) - \mathbf{w}^T\,\mathbf{r_d}(n)] * c(n)\}^2 \tag{2}$$

where E is the standard statistical expectation, "*" is the convolution operator, and

$t(n)$ = target signal
$\mathbf{r_d}(n)$ = $[r_d(n),\ldots,r_d(n-M+1)]^T$
= delay-corrected tracking vector
$c(n)$ = performance filter impulse response
D = equalizer delay

The delay D has been introduced for anticausal operations. It must be greater than the mean tracking delay. Normally the equalizer should not change the joystick gain, thus the constrain $\mathbf{w}^T\mathbf{u} = 1$ must be imposed (**u** here is a vector of ones). It can be shown [3] that, under this constrain, the optimal **w** is given by the Wiener solution

$$\mathbf{w} = \mathbf{R}^{-1}\{\mathbf{p} + (1 - \mathbf{u}^T\mathbf{R}^{-1}\mathbf{p})\,\mathbf{u} / (\mathbf{u}^T\mathbf{R}^{-1}\mathbf{u})\} \tag{3}$$

where **R** is the autocorrelation matrix of the *performance-filtered* $\mathbf{r_d}$ and **p** is the vector of cross-correlations between *performance-filtered* $\mathbf{r_d}$ and delayed *performance-filtered* target.

However, since the signals are slow (to allow tracking), the matrix **R** becomes highly ill-conditioned and the Wiener solution is often unstable and not reliable. Matrix condition can be greatly improved with the high frequency enhancement of the differentiator. Results show, however, that this is not sufficient.

To overcome this problem a modified optimization method is proposed by noting that for a coherent tracking task, the delay-corrected tracking signal must look similar to the target. This means that the impulse response of an optimal and robust equalizer should be close to δ(n-D), namely, an impulse delayed by D. Hence, the Wiener solution is *pulled* closer to δ(n-D) by changing the minimization criterion to

$$\min\,\{\text{F-MSE}_d(\mathbf{w}) + \alpha\,[\mathbf{w} - \delta(n-D)]^T[\mathbf{w} - \delta(n-D)]\} \tag{4}$$

where α is a positive parameter, small enough to not significantly affect F-MSE$_d$, but large enough to *pull* **w**. It can be shown that the solution to this problem is obtained substituting **R** and **p** by **R**+α**I** and **p**+$\alpha\delta$(n-D) respectively in (4). A recommended value for α is $(Sf_t - \mathbf{p}^T\mathbf{R}^{-1}\mathbf{p})/M$ where Sf_t is the filtered target power. We call this technique *pulled-optimization*, and can be viewed as a generalization of the tap-leakage technique used in Communications to give stability to equalizers.

Results

Experiments for designing and evaluating the equalizers were performed by inducing a tremor with a 4 Watt motor that was attached to a normal subject's hand. The high performance of the equalizer in suppressing off-line tremor is clear in Fig. 3. In effect, Table I shows that the equalizer, working off-line, has reduced the F-MSE$_d$ by almost 90%. It is worth to note that while tremor is evidently reduced, the MSE$_d$ remains practically unchanged, indicating that even after delay correction, the plain MSE with no performance-filter is not a good indicator of performance, at least for the problem of tremor suppression.

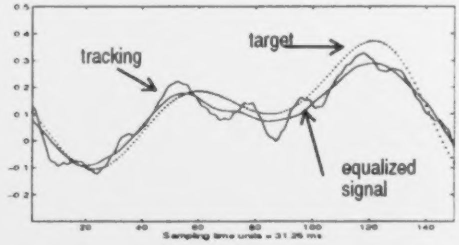


Fig. 3. Typical segments of the aligned target, tracking, and off-line equalized signals.

In practice, the equalizer designed off-line is incorporated in the experiments on-line. Since off-line equalization ignores human feedback, it must be proven that the equalizer, although designed to maximize off-line performance, actually suppresses tremor when incorporated as an active on-line element in a man-machine system with feedback. Twelve pursuit tracking tasks were performed, six with equalizer and six without. The mean F-MSE$_d$ reported in Table I, shows a 70% in performance improvement when the equalizer was on-line. In addition, a writing test was performed, in which the subject had to write a word on the screen of the computer by controlling the cursor with the joystick. The result in Fig. 4 speaks for itself.

	Without Equalization	Off-line Operation	On-line Operation
F-MSE$_d$	.00087	.00009	.00023
MSE$_d$	.00917	.005	.011

Table I. Comparative performance measures for off-line and on-line equalizer operation.

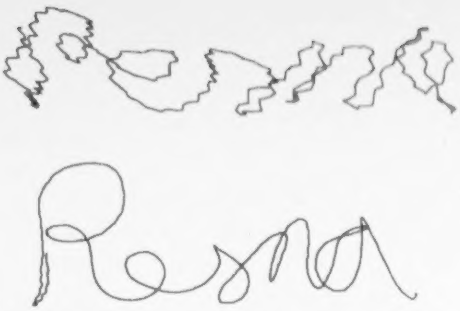


Fig. 4 Writing test. Top: a trial without using equalization. Bottom: trial using the equalizer described in the paper.

Discussion

A new technique for suppressing tremor has been proposed and tested successfully with artificially created tremor. A more appropriate approach to the problem of performance evaluation in the context of tremor has been developed and used for designing tremor equalizers. These results could be significant in the development of improved manual input devices such as wheelchair controllers or general purpose joysticks for people with tremor.

Much work is still to be done in experimenting and validating the equalizers with real subjects, investigating more deeply the performance filters, designing adaptive and nonlinear equalizers, and combining the equalizers with mechanical filters.

References

1. Arnold A. S. et al., (1993) *Evaluation of a Controlled-energy-dissipation Orthosis for Tremor Suppression*. Jour. Electromyography and Kinesiology, V. 3, No.3, pp.131-148.

2. Etter D. and Stearns S., (1981) *Adaptive Estimation of Time Delays in Sampled Data Systems*, IEEE Trans. on ASSP, V. 29, No. 3, pp. 582-587.

3. Gonzalez J. G. (1995, In Preparation) *A New Approach to Suppressing Abnormal Tremor Through Signal Equalization and Mechanical Filtering*. Master's Thesis. Dep. Electr. Eng., University of Delaware, Newark, DE.

4. Hendricks J. L. et al, (1991) *A Second Generation Joystick for People Disabled by Tremor*. Proc. 14th RESNA Ann. Conf., pp. 248-250.

5. Riley P. O., and Rosen M. J.(1987) *Evaluating Manual Control Devices For Those With Tremor Disability*. Jour. Rehab. Res., V. 24, No. 2, pp. 99-110.

6. Sheridan T. B. and Ferrel W. R. (1974) *Man-Machine Systems*, MIT Press, Cambridge, MA.

Acknowledgments

The authors wish to acknowledge support from the National Institute on Disability and Rehabilitation Research, U.S. Department of Education, under Grant #H133E30013 and Nemours Research Programs.

Juan Guillermo Gonzalez
Applied Science and Engineering Laboratories
P.O.Box 269 - Wilmington DE, 19899
e-mail: gonzalez@asel.udel.edu

BEST COPY AVAILABLE

Kinematic Analysis and Bandwidth Requirements of Sign Language

Edward Walsky, Richard Foulds Ph.D.
University of Delaware / A.I. duPont Institute
Applied Science and Engineering Laboratories

Abstract

It has been found that in video and animated sequences, a frame rate of 12 to 15 frames a second is needed for intelligibility of displaying sign language. It was thought that this rate was essential for adequately representing the frequency spectrum of the movements which comprise the signs. However, in this study of the frequency content of selected signs, it was found that the essential frequency content for intelligibility lies in the 0-6hz range and that employing a lowpass filter to the kinematic data of sign language at 4-6hz and above produced no change in the intelligibility of the studied signs. This has the affect of lowering the bandwidth needed to produce understandable signing. Although the display rate still needs to be at 12-15 hz, the sampling rate can be lowered to 4-6hz.

Background

Three quarters of a million people use sign language as a first language in the United States. It is a sequence of complex gestures using the fingers, hands, wrists and arms in its own syntax to convey thoughts. The scientific study of sign language began in the late 1950's primarily focusing on its linguistic features (1). The motions themselves have received limited study. In the 1960's, a way of quantifying the motions of sign language was discovered (2) and in the 1970's, the anatomical constraints of sign language were studied (3). Neither of these studies made no attempt to look at the kinematics of signing. It was not until 1983 that the spectrum of movements was studied (4), but the relationship of the signal content to intelligibility was till not addressed.

The motions of signing are especially important in the transmission of video data over existing phone lines. Phone lines have two different formats: POTS, or Plain Old Telephone System, allows up to 28.8 kilobaud of digital transmission and ISDN, a new digital standard, popular in Europe and now gaining acceptance in the U.S., allows up to 64 kilobaud of digital transmission. Both systems, however, fall well short of the 40 megabaud needed to adequately transmit video data (5). In an effort to reduce the needed bandwidth, it was shown that it was not the image quality but the fidelity of movement that was the key factor in the interpretation of movement. Edge detected images were used showing no more than 1000 pixels per display at 15 to 30 frames/sec. This proved to be approximately as intelligible at VHS quality video (6). As the frame rate was lowered, the intelligibility rate also dropped. Their conclusion was that a minimum frame rate of 12 to 15 frames/sec was needed to avoid a degradation of movement.

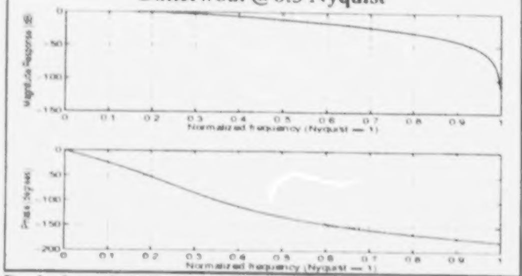
Research Questions

From these studies, it could be surmised that essential sign language motion lies at or below 12 to 15 hz. It is our thesis that the actual essential spectrum is significantly less than 12 to 15 hz and, as such, could help reduce the needed bandwidth for a video telephone. We will also look at the impact of retaining these essential frequencies and will speculate on an expected data rate.

Method

The facilities at the ASEL Gesture Laboratory were used to study the frequency response of the hand and fingers. Two Virtual Technologies Cybergloves measuring 18 finger and wrist angles were used along with 2 Ascension Technologies Bird sensors for wrist position and orientation. Both the gloves and Birds were sampled at 25 hz, although only the data from the dominant hand was used (the right hand in this case). An experienced signer was fitted with this apparatus and asked to sign selected signs. The data was collected on a Silicon Graphics Indigo and was processed using MATLAB on a Sun Sparcstation. To plot the power spectra, the data was prepared with a hamming window before performing the fourier transform. Filtering was performed within MATLAB by using a first order butterworth filter. All data was filtered both forward and backward to avoid phase changes and, as a side effect, doubling the order of the filter. The filter characteristics for a 2nd order lowpass butterworth filter @ 0.3 times the Nyquist frequency are given below:

FIGURE 1: Filter Characteristics 2nd Order Butterwoth @0.3 Nyquist



Both the original and filtered data were displayed with an animated torso with fully articulated hands and fingers on an Silicon Graphics Workstation.

Spectral Content of Sign Language

Pilot Study

To illustrate the underlying basis of this paper, a pilot study was done in which the subject was asked to repeatedly trace a rectangle in a plane parallel to the torso (the X-Y plane where X is left and right, the Y is up and down) at a comfortable rate. Data was sampled at 25 hz. The rectangular shape was chosen for its high and low frequency components. Low frequencies correspond to the fundamental frequency of repetition and the general shape of the rectangle. High frequencies correspond to rapid direction changes (the corners of the rectangle). The original data of the X-Y position of the wrist is presented in Figure 2 and the power spectra in Figure 3.

FIGURE 2: Y vs X Wrist Positions-Tracing Square

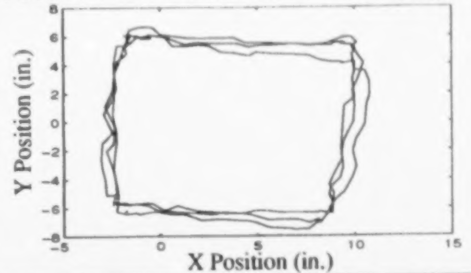
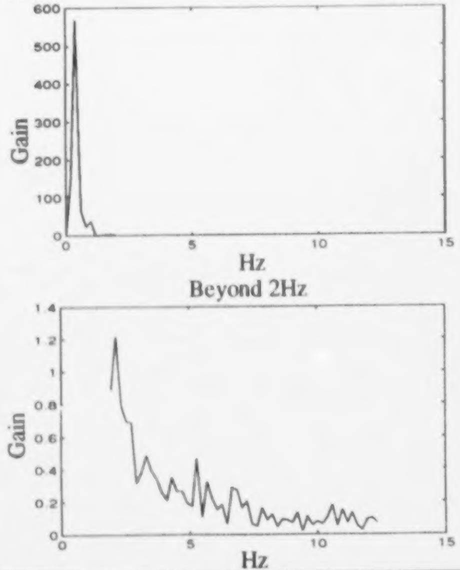
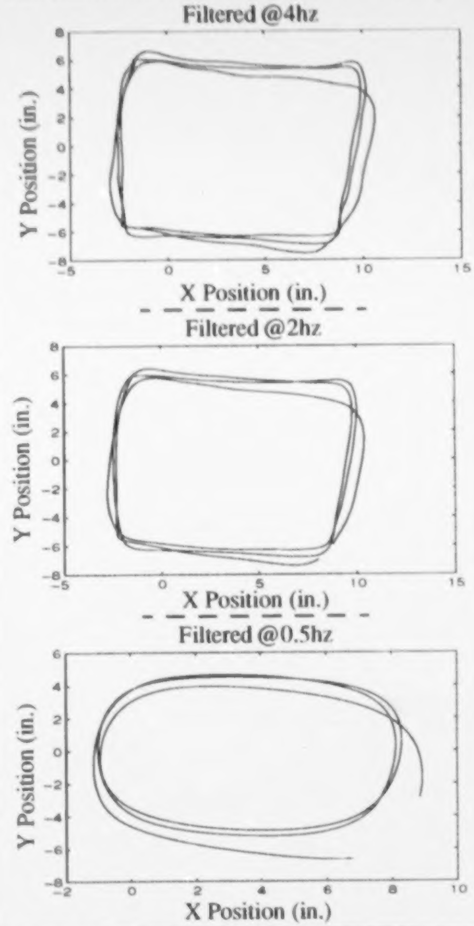


FIGURE 3: Power Spectra-Y axis-Tracing Square



In Figure 3, the fundamental frequency of the square, about 0.4 hz, dominates the spectrum. This is the frequency at which the square was traced, 1 square every 2.5 seconds. Also in Figure 3 is a close-up of the frequency response beyond the 2 hz range. This graph shows the contribution of the high frequencies in creating the square. The data were subsequently lowpass filtered at 4, 2 and, 0.5 hz shown in Figure 4.

FIGURE 4: Y vs X Wrist Positions-Tracing Square

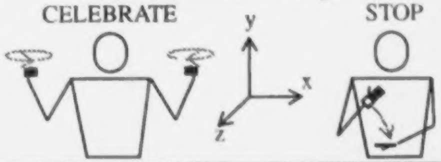


It is evident that even at 4 hz, the rectangle is still easily recognizable. As can be seen, when the filtering is done at 0.5 hz, the rectangle gets sufficiently distorted as to not be recognizable.

Results

Two representative signs were collected with the gloves and birds. The signs chosen were CELEBRATE (waving the hands in small circles about the head as if holding flags in them) and STOP (a sharp chop of one hand into the palm of the other [see Figure 5]). STOP was repeated several times to give both signs repetitive motion and similar durations. Figure 6 shows the spectra for these signs. It is clear from these

FIGURE 5: Selected Signs

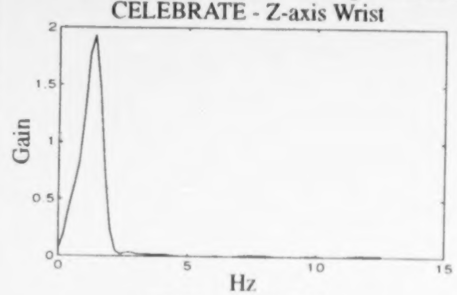


BEST COPY AVAILABLE

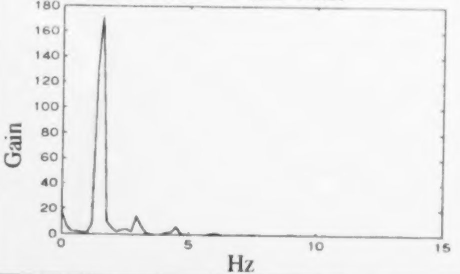
spectra that there is little frequency content above 4 hz. The abrupt direction change with STOP, as one hand hits the other, produces some higher frequency content. This may be due to the reverberation of the hand at impact and not part of the meaning of the sign.

FIGURE 6: Power Spectra of Signs Studied

CELEBRATE - Z-axis Wrist



STOP - Y-axis Wrist



The data were animated on a Silicon Graphics Reality Engine using software developed for sign language synthesis using the full capabilities of a 3D graphics environment. Animations were of the original data, filtered at 6hz and at 4hz. An evaluation of the signs by observers of the filtered animations at 6hz and 4hz showed little or no degradation. Compared to the animation of the unfiltered data, a formal experimental design to study the intelligibility of the animations was not conducted as there was complete agreement among the observers.

Discussion

The pilot study and the retention of intelligibility of the two signs studied suggest that the frequencies of interest lie in the 0-6hz range instead of the 12 to 15hz range previously thought necessary. The implication of this statement is that sign language could be transmitted at 4-6 frames/sec. However, the display of signs must remain at 12-15hz to maintain the continuity of the sign and avoid the flicker and jerkiness of lower frame rates.

An opportunity exists to study how to reconstruct the transmission of 4-6 frames/sec to a display rate of 12 to 15 frames/sec or higher. Such a paradigm would greatly decrease the needed bandwidth of a video telephone.

One potential problem could be finger spelling which can have rates higher than signing rates and this may be too fast for the 4-6 hz transmission rate. This could be rectified by ignoring the non-dominant hand and increasing the sampling rate for the dominant hand if it is found not to be moving in space.

An estimate of the bandwidth needed could be summarized as:

Table 1: Transmission Rate Estimate

Measurement	Number of Measurements	Bytes per Measurement	Total for Both Hands
Finger Angles	18	1	36
Wrist Position	3	2	12
Wrist Angles	3	1	6

At 4 frames a second, this translates to 216 bytes per second or 1728 bits per second!

Is it the fate of sign language to be transmitted by only a 2400 baud modem?

References

(1) Klima, Edward, U. Bellugi: The Sings of Language. Harvard University Press, 1979.

(2) Poziner, Howard, E. Klima, U. Bellugi, R.B. Livingston: Motion Analysis of Grammatical Processes in a Visual Language. Association for Computing Machinery, 1983, pp.148-171

(3) Stokoe, William C., D. C. Casterline, C. G. Croneburg: A Dictionary of American Sign Language on Linguistic Principles, Linstok Press, 1976.

(4) Mandel, Mark A., Natural Constraints in Sign Language: Data From Anatomy, Sign Language Studies 24. Linstok Press Inc, 1979, pp 215-229.

(5) Galuska, S., Gove, T., Gray, J.: A Visual "Talk" Utility: Using Sign Language Over a Local Area Computer Network. Proceedings of the RESNA International '92 Conference, 1992, 143-135.

(6) Harkins, J., A, Wolff, A., Korres, E., Foulds, R., Galuska, S., Intelligibility Experiments with a Feature Extraction System Designed to Simulate a Low-Bandwidth Video Telephone for Deaf People. Proceedings for the 14th Annual RESNA Conference, 1991, 38-40.

Acknowledgments

The research was supported in part by the Rehabilitation Engineering Research Center on Augmentative Communication - Grant # H133E30010 of the NIDRR and the Nemours Research Programs.

Author address

Edward Walsky
A.I. duPont Institute / University of Delaware
Dept. of Applied Science and Engineering
1600 Rockland Rd.
Wilmington, De. 19899
(302)-651-6830
walsky@asel.udel.edu

Identification of Cortical Signal Patterns Related to Human Tongue Protrusion

Jane E Huggins

Please refer to the Research Symposium paper, page 670

Simulations of User Performance with Word Prediction

Heidi Horstmann Koester and Simon P. Levine
Rehabilitation Engineering Program, Graduate Bioengineering Program
University of Michigan

Abstract

Previous work has demonstrated that, under well-defined conditions, a quantitative model can accurately represent user performance with word prediction systems [1,2]. This paper illustrates the use of this model to simulate user performance across a range of conditions. Examples of simulation results are presented to show how user characteristics, strategy of use, and system characteristics combine to determine overall performance. The use of model simulations to inform clinical decision-making and research questions is discussed.

Introduction

Development of quantitative models of user performance has been a longstanding research interest in AAC and computer access. Accurate simulations of user performance can potentially aid developers and clinicians with:

- system design, by predicting the effect of system characteristics on performance;
- system recommendation, by simulating the expected performance of a particular user with candidate systems;
- system delivery and training, by simulating how system configuration and strategy of use might affect performance.

Our work to date has focused on word prediction systems. In a recent model validation study, a simple model of user performance was developed and tested against the actual performance of eight able-bodied and six spinal cord injured subjects. Given the search strategy to be employed and measured estimates of the user's keypress and list search times, model error averaged 9.2% for overall text generation rate with word prediction and 16.5% for individual word entry times [1,2].

The accuracy of these model simulations provides some confidence that the model can help determine when word prediction will provide faster text generation rate than letters-only typing. The key factors represented in the model are the characteristics of the user, the strategy used to search the word list, and the configuration of the word prediction system. While simulations across any of these dimensions are possible, we focus here on two examples of model simulations in order to illustrate the basic approach.

Simulation Methods

Model Equations

Equations for the text generation rates with letters-only typing and word prediction were derived as follows. Text generation rate with letters-only typing (TGR_{lo}) is simply the user's keypress time (t_k) expressed in characters per minute:

$$TGR_{lo} = 60/t_k \qquad \text{char/min.} \quad (1)$$

To model word prediction use, the time the user requires to search the word list (t_s) must be considered, in addition to the keypress time. The average time necessary to generate each character is modeled as the sum of two components: the number of list searches per character (S) multiplied by the search time and the number of keypresses per character (1-ksav) multiplied by the keypress time. (*Ksav* is the keystroke savings provided by the word prediction system, expressed as a proportion rather than a percent; the equation is expressed in terms of ksav because it is a common benchmark of system performance.)

The model must also account for the empirical observation that keypress time during use of word prediction can be significantly slower than during letters-only typing [1,2]. This "keypress delay" effect is represented by a third user parameter, *d*, defined as the amount of extra time required for the keypress action during use of word prediction relative to letters-only. Converting units from seconds per character to characters per minute, the resulting equation for text generation rate with word prediction (TGR_{wp}) is:

$$TGR_{wp} = \frac{60}{(S)(t_s) + (1 - ksav)(t_k + d)} \qquad \text{char/min.} \quad (2)$$

As can be seen from Equation (2), text generation rate is a multi-dimensional space, which makes it difficult to determine the unique effects of each parameter. The three user parameters (t_s, t_k, d) are independent of each other, and the two system parameters (S, ksav) are jointly determined by the system configuration and the search strategy used. To keep the simulations manageable and interpretable, parameters for the example simulations presented here were constrained as defined below.

Simulation Constraints

User parameters. Measurements from the model validation study [1,2] provide one basis for defining a range of expected user parameter values. The average values for able-bodied subjects were $d = 0.1$ sec, $t_k = 0.8$ sec, $t_s = 0.5$ sec. For spinal cord injured subjects, the average values were $d = 0.3$ sec, $t_k = 0.6$ sec, $t_s = 1.1$ sec. In the example simulations below, keypress delay (d) is fixed at 0.1 sec, and keypress and list search times range from 0 to 2 seconds.

Word prediction strategies. Six text entry methods were examined: letters-only and five word prediction strategies. Rules for the five word prediction strategies were to always search the list (AS) and search after entering 1, 2, 3, or 4 letters (1S, 2S, 3S, 4S, respectively). All strategies assume that the search process is discontinued if the word is not found by the fifth letter.

System characteristics. This paper focuses on a configuration for word prediction which yields approximately the average keystroke savings reported for commercial word prediction systems (42%) [3]. The system parameters for the five word prediction strategies were computed for the text used in the validation study and are shown in Table 1.

Strategy	Searches/char (S)	Keypresses/char (1-ksav)
always-search	0.476	0.587
1-then-search	0.326	0.617
2-then-search	0.210	0.701
3-then-search	0.114	0.790
4-then-search	0.057	0.862

Table 1. Parameters for "average" WP configuration.

Simulation Results

Example 1: Performance Profile

A "performance profile" displays the relative performance of the word prediction strategies with respect to each other and letters-only typing. Performance profiles were generated by simulating the text generation rate (Equations 1 and 2) for each strategy and letters-only typing across the defined range of keypress and list search times. The resulting rates were then compared over the space of user parameter values to determine the fastest method in each region of the space. An example performance profile is shown in Figure 1.

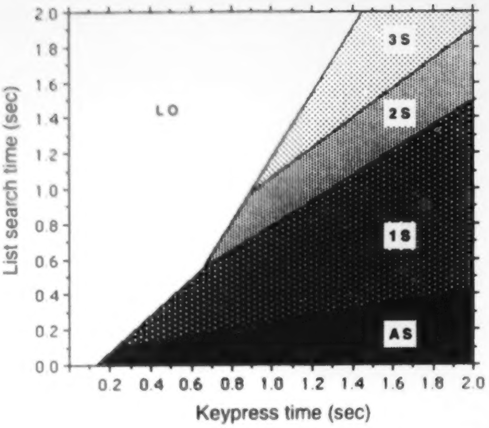


Figure 1. Performance profile, showing regions where each of the word prediction strategies and letters-only typing is predicted to provide the best performance. Average keystroke savings and a keypress delay of 0.1 seconds are assumed.

Each wedge in the profile represents the region in (t_k, t_s) where a particular text entry method gives better performance than the other five. For example, for any combination of t_k and t_s that falls in the wedge labelled "AS", the "always-search" strategy is predicted to give faster performance than either letters-only typing or any of the other word prediction strategies examined. According to the profile, a user whose keypress time is 0.8 seconds would need a search time less than 0.2 seconds in order for "always-search" to be the preferred strategy. A user with a keypress time of 0.8 seconds and a search time of 0.5 seconds should use the "1-then-search" strategy for the best performance. "1-then-search" has the biggest region in which it is dominant, which suggests it may be a good all-purpose strategy for users with a variety of characteristics. The "4-then-search" strategy is not represented on the profile, indicating that it is not a preferred strategy under any of the conditions here.

The profile can also be used to make more general comparisons between letters-only and word prediction. The region labeled "LO" shows where letters-only provides better performance than any of the five word prediction strategies. The remaining shaded region is where some form of word prediction use will give the best performance. For a user with $t_k = 0.8$ seconds, letters-only should be used if t_s exceeds 0.9 seconds. As keypress time gets faster, the cut-off search time also decreases; for $t_k = 0.5$ seconds, for example, search time would have to be below 0.4 seconds for some form of word prediction to be beneficial.

BEST COPY AVAILABLE

723

Example 2: Effect of User Parameters

The performance profile provides valuable information on relative performance between strategies, but it does not show the actual performance to be expected, or how that performance changes with user parameters. The next example focuses on the expected performance with the "1-then-search" strategy, which the profile above suggests as a good all-purpose strategy. Again, average keystroke savings and a keypress delay of 0.1 seconds are assumed. Figure 2 illustrates how the expected improvement in text generation rate with word prediction relative to letters-only typing depends on the user's keypress and list search times.

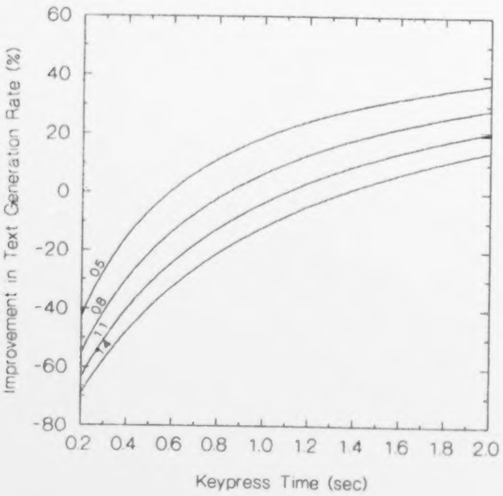


Figure 2. Improvement in text generation rate as a function of keypress time for the "1-then-search" strategy. Each curve represents a fixed level of list search time, from 0.5 to 1.4 seconds.

Based on Figure 2, a user with a keypress time of 1.2 seconds and a list search time of 0.5 seconds should be able to generate text over 20% faster with word prediction as compared to letters-only. If this same user's search time were actually 1.1 seconds, the text generation rate improvement expected with word prediction would be less than 5%.

Discussion

These examples illustrate how model simulations can estimate the effects of search strategy and user characteristics on user performance with word prediction. The same simulation techniques can be used to examine situations other than those shown in the examples by using different parameter values to represent the condition of interest.

A challenge in using these simulations to inform clinical and design practice is choosing appropriate values for the user parameters. To obtain point estimates of these parameters, it may be possible to employ direct measurement in a clinical situation. This would be quite straightforward for keypress time but more difficult and time-consuming for the parameters of keypress delay and list search time. Parameter choice can also be informed by the values measured for subjects in the validation study, to complement direct measurement and to provide a basis for modeling in design situations where specific individual measurements are not available.

It should be noted that these simulation results (and others based on this model) apply with the greatest confidence to conditions similar to those under which the model was validated. Further work is necessary to determine the extent to which the modeling approach is valid for: users who have variable motor control and/or cognitive impairments, natural strategies of system use, and systems other than word prediction.

Conclusions

User performance with word prediction is a function of user characteristics, strategy of system use, and system characteristics. Model simulations are one way to determine the influence of each of these factors on performance time.

References

1. H. Horstmann Koester. "User Performance with Augmentative Communication Systems: Measurements and Models," Doctoral Dissertation, University of Michigan, 1994.

2. H. Horstmann Koester and S.P. Levine. "Text Entry Performance with a Word Prediction Interface," in *IEEE Transactions on Rehabilitation Engineering*, vol. 2, no. 3, pp. 177-187.

3. D.J. Higginbotham. "Evaluation of Keystroke Savings across Five Assistive Communication Technologies," in *AAC*, vol. 8, no. 4, pp. 258-272.

Acknowledgments

This research was supported by the National Science Foundation, Rackham School of Graduate Studies, and the Rehabilitation Engineering Program at the University of Michigan.

Heidi Horstmann Koester, Ph.D.
1C335 University Hospital
Ann Arbor MI 48109-0032
Internet: hhk@umich.edu

POSTIONAL DEPENDENCE OF THE RECRUITMENT PROPERTIES OF NERVE CUFF STIMULATING ELECTRODES

Warren M. Grill and J. Thomas Mortimer
Applied Neural Control Laboratory, Department of Biomedical Engineering
Case Western Reserve University, Cleveland, OH USA

ABSTRACT

Changes in the recruitment properties of a multiple contact nerve cuff electrode at different limb positions were measured in an animal model. Immediately after implantation, the recruitment properties changed with limb position indicating that the cuff was moving relative to the nerve fibers. After 8 weeks of implantation, sufficient time to allow fibrous tissue encapsulation of the electrode, the recruitment properties were no longer dependent on limb position. This suggested that tissue encapsulation acted to stabilize the cuff electrode, eliminating any position dependent recruitment properties. This is an advantage over presently used muscle-based electrodes. Stable input-output properties should simplify user control of motor prosthetic devices and thus improve function.

BACKGROUND

Electrical stimulation of the nervous system is a rehabilitation method to restore functional movement to persons paralyzed by stroke, spinal cord injury, or head injury [7]. Present motor prosthesis systems employ muscle-based electrodes to excite lower motor neurons and generate muscular contractions. These electrodes have been used to generate functional movement of the upper extremity for grasp and release and movement of the lower extremities for standing and stepping. Muscle based electrodes, however, suffer from limb-position-dependent input-output characteristics that can complicate prosthetic control.

Input-output properties, or recruitment characteristics, describe the relationship between the evoked muscle force and the stimulus amplitude or pulsewidth. Muscle-based electrodes have recruitment characteristics that are dependent on the position of the limb. During changes in limb position, muscles change length and the electrode is displaced relative to the motor nerves that are to be activated. Electrode movement changes the distance between the electrode and the excitable tissue, causing position dependent variations in muscle recruitment [1, 3]. Position dependent recruitment makes recruitment level a non-unique function of the stimulus parameters, creates regions of high and variable gain, and may limit range of motion by creating instabilities. In cases where the motor prosthesis user voluntarily grades the stimulus parameters, position-dependent recruitment properties have produced poor control characterized by deadbands, overshoot, and hunting behavior [5].

Cuff electrodes provide an alternative technology to activate lower motor neurons for motor prosthetic applications. We have previously demonstrated, using multiple contact nerve cuff electrodes, selective and independent control of force generation in multiple muscles innervated by a large nerve trunk [4, 8]. The purpose of the present investigation was to measure changes in the recruitment properties of cuff electrodes that occurred as a result of changes in limb position.

RESEARCH QUESTIONS

The specific objective of this research was to determine the effects of joint angle changes on the recruitment properties of nerve cuff stimulation. We asked two questions: do the recruitment properties of cuff electrodes depend on limb position ? and does the degree of position-dependent recruitment change after the cuff is surrounded by encapsulation tissue ?

METHODS

Experiments were conducted in an animal model to measure the position dependence of the recruitment properties of multiple contact nerve cuff electrodes. All animal care and experimental procedures were according to NIH guidelines and were approved by the Institutional Animal Care and Use Committee of Case Western Reserve University. Silicone rubber spiral nerve cuff electrodes, containing 12 individually addressable platinum electrode contacts [8], were implanted on the right sciatic nerve of adult cats. In this report, data are included from 5 acute experiments and 8 chronic experiments.

Experimental Procedures: In acute experiments, animals were initially anesthetized with ketamine hydrochloride (35 mg/kg, I.M.), and maintained with sodium pentobarbital (5-10 mg bolus injections, I.V.). For measurements with chronically implanted nerve cuff electrodes, animals were initially anesthetized with xylazine (Rompun, 2.0 mg/kg, S.Q.), and maintained with 1.5-2.0% gaseous Halothane in O_2.

Animals were mounted in a stereotaxic apparatus designed to measure the isometric torque generated at the ankle joint by stimulation of the sciatic nerve [4]. Twitch contractions in the ankle musculature were generated using controlled current rectangular pulses applied at 0.5 Hz through longitudinal tripolar electrode configurations. The evoked torque signals were low pass filtered at 100 Hz and sampled at 200 Hz. Recruitment curves of joint torque as a function

725

of stimulus current amplitude were measured at three ankle joint angles (70°, 90°, and 110°).

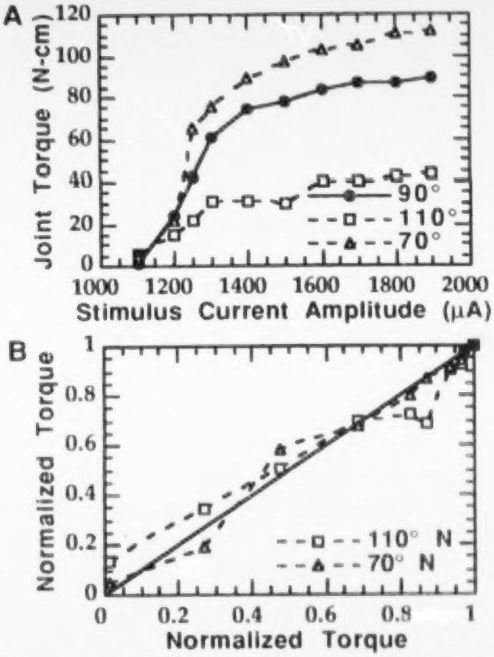


Fig. 1: A. Recruitment curves of plantarflexion torque collected at three different ankle joint angles in 1 acute experiment. **B.** Positional dependence of the recruitment characteristics appeared as deviations of the normalized data points from the unity slope line.

RESULTS

Isolation of Position Dependent Recruitment: Recruitment curves of plantarflexion torque as a function of stimulus current amplitude at three different positions of the ankle joint (70°, 90°, 110°) are shown in fig. 1A. The changes in torque as the joint angle changed arose from three different sources. First, the torque magnitude increased when the active muscle was stretched and decreased when the active muscle was shortened, as a result of the intrinsic length-tension properties of skeletal muscle [6]. Second, torque output was affected by muscle moment arms that are known to depend on joint position [9]. Finally, changes in torque output arose from changes in the spatial relationship between the stimulus field and the excitable fibers due to relative movement between the electrode and the motor nerve fibers (i.e., position-dependent recruitment).

Each recruitment curve was normalized, by dividing by the maximum torque, to eliminate the effects of length-tension properties and joint-angle-dependent moment arms [1]. The normalized torques at 70° and 110° were plotted as a function of the normalized torque at 90° with stimulus amplitude as the independent variable (fig. 1B). Position-dependent recruitment was quantified by determining the deviations of the measured points from the unity slope line, as a percentage of the maximum torque.

Positional Stability in Acute Implants

The distribution of the position-dependent recruitment deviations from 28 pairs of recruitment curves collected in five acute experiments is shown in fig. 2 (one pair consisted of a curve measured at 90° and a curve measured at ±20°). The deviation (|% deviation|=8.8±9.8%, mean±s.d., n=209 points) was not correlated with either the relative torque magnitude (r^2=0.011) or the absolute torque magnitude (r^2=0.021). Additionally, the deviations were not significantly different between cases where the active muscle was either lengthened or shortened, (p=0.5606, t-test), and the deviation did not depend on the direction of joint angle change (p=0.4184, t-test). The mean deviation between repeated measurements at the same joint angle, before and after a static change in joint angle, (|% deviation|=13.2±15.5%, n=55 points over 8 recruitment curves in 3 animals) was significantly larger than the mean error between measurements at 2 different joint angles (p=0.0052, t-test). These results indicated that the deviations were caused by small shifts in electrode position that occurred when the joint angle was changed.

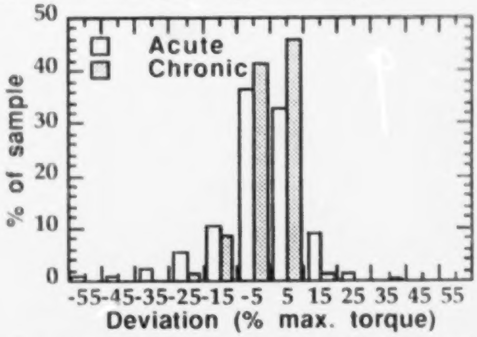


Fig. 2 Histogram of position-dependent deviations in recruitment characteristics measured in acute and chronic implants.

Positional Stability in Chronic Implants

In contrast to the results obtained during acute experiments, chronically implanted cuff electrodes exhibited recruitment properties that did not change with changes in limb position. Recruitment curves of plantarflexion torque as a function of stimulus current amplitude are shown in fig. 3 from 1 experiment with a chronically implanted cuff. The torque magnitudes changed as the joint angle changed, as expected from the length-tension properties [6] and joint-angle-dependent moment arms [9]. However, the shape of the three curves was very similar at all positions. There was no change in either the threshold currents, or the current amplitudes at which spillover occurred (second rise in recruitment curves). The similarity among the three recruitment curves at different positions indicated that the same motor nerve fibers were being stimulated, and thus that there was no relative movement between the electrode and the nerve fibers at different limb positions.

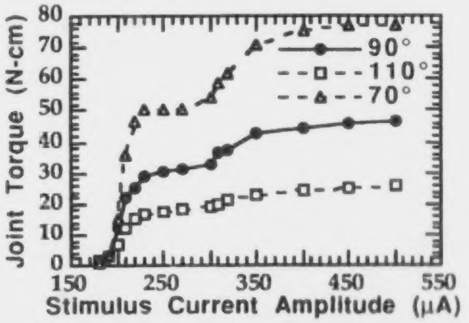


Fig. 3 Recruitment curves of plantarflexion torque measured at three ankle joint angles in 1 experiment with a chronically implanted cuff electrode.

The analyses described for the acute data were repeated for 26 pairs of recruitment curves from 8 experiments in 3 chronic animals. These recruitment curves were collected at least 8 weeks post- implant to ensure that tissue encapsulation had formed around the electrode. A histogram of the position-dependent deviations in recruitment characteristics measured in the chronic experiments is shown in fig. 2. The absolute value of the deviation in the chronic implants ranged between 0 and 34% of the maximum torque (|%deviation|= 5.0±5.0%, n=327 points). The mean deviation was significantly smaller in the chronic measurements than in the acute measurements ($p<0.01$, Mann-Whitney U-test). These results indicated that the recruitment properties of encapsulated cuffs were stable at different limb positions.

DISCUSSION

In these experiments the changes in nerve cuff recruitment properties that occurred at different limb positions were quantified. Recruitment properties of acutely implanted cuff electrodes, which were not surrounded by tissue encapsulation, were position dependent. Although 80% of the deviations in the acute measurements were less than 20% of the maximum torque, this amount of position dependence was not expected. A previous report indicated that changes in muscle length did not affect recruitment properties [2]. The changes in joint angle used in the present study, however, are more like limb movements that would occur during application of a cuff electrode in motor prostheses systems. These results indicated that acutely implanted cuff electrodes may move relative to the underlying motor nerve fibers as a result of changes in limb position.

Experiments with chronically implanted cuff electrodes indicated that the recruitment properties were stable with changes in limb position. Histological analyses of explanted cuff electrodes revealed that the chronically implanted cuff electrodes were surrounded by a thin (≤300μm) layer of fibrous connective tissue containing fibroblasts and collagen. These results suggest that the tissue encapsulation stabilized the electrode position, and thus reduced the degree of position dependent recruitment.

Cuff electrodes, once encapsulated, have recruitment properties with a much smaller degree of position-dependence than muscle-based electrodes. The absence of position-dependent recruitment should simplify user control of motor prosthetic systems employing cuff electrodes by eliminating regions of variable gain. More stable recruitment properties should improve the function of motor prostheses for rehabilitation of neurologically impaired individuals.

REFERENCES

[1.] Crago, P.E., P.H. Peckham, G.B. Thrope (1980) Modulation of muscle force by recruitment during intramuscular stimulation. IEEE T-BME 27:679-684.

[2.] Durfee, W.K., K.I. Palmer (1994) Estimation of force-activation, force-length, and force-velocity properties in isolated electrically stimulated muscle. IEEE T-BME 41:205-216.

[3.] Grandjean, P.A., J.T. Mortimer (1986) Recruitment properties of monopolar and bipolar epimysial electrodes. Ann. Biomed. Eng. 14:53-66.

[4.] Grill W.M., J.T. Mortimer (1993) Functional control of joint torque with a cuff electrode. Proc. 15th Int. Conf. IEEE-EMBS 15(3):1328-1329.

[5.] Hines, A.E., N.E. Owens, P.E. Crago (1992) Assessment of input-output properties and control of neuroprosthetic hand grasp. IEEE T-BME 39:610-623.

[6.] Rack, P.M.H., D.R. Westbury (1969) The effects of length and stimulus rate on tension in the isometric cat soleus muscle. J. Physiol. 204:443-460.

[7.] Stein, R.B., P.H. Peckham, D.B. Popovic (1992) Neural Prostheses: Replacing Motor Function After Disease or Disability,, Oxford University Press, NY.

[8.] Veraart, C., W.M. Grill, J.T. Mortimer (1993) Selective control of muscle activation with a multipolar nerve cuff electrode, IEEE Trans. Biomed. Engineering 40:640-653.

[9.] Young, R.P., S.H. Scott, G.E. Loeb (1992) An intrinsic mechanism to stabilize posture: joint-angle-dependent moment arms of the feline ankle muscles. Neurosci. Lett. 145:137-140.

ACKNOWLEDGEMENTS

This work was supported in part by a grant from the Paralyzed Veterans of America Spinal Cord Research Foundation and by NIH NINDS Neural Prosthesis Program Contract No. NS-01-3-2300. The authors thank Mr. Dustin Tyler for assistance during the acute experiments, and Ms. Nancy Caris and Ms. Jennifer Crossen for assistance during the chronic experiments.

Warren M. Grill (wmg@po.cwru.edu)
Applied Neural Control Laboratory
Case Western Reserve University
C.B. Bolton Bldg., Rm 3480
Cleveland OH 44106-4912 USA
(216) 368-2948

Student Design Competition

1995 Student Design Competition
Project Submissions

The Development of an Extendable Below-Knee Pediatric Prosthesis Randy Bernard, Ohio St Univ, Columbus, 614/293-3808

*Design of Work Jigs to Assist the Disabled in Sheltered Workshops in the Production of Sample Display Chains Robert Cavin, Irem Turner, Mark Foohey, Univ Texas at Austin, 512/471-0095

Adapting the Game of Hockey Amanda Van Deusen, So Torrance High School, Torrance, CA, 310/940-7994

*Tactile Sensing for Prosthetic Arms Warren D'Souza, Henry O'Beirne, Stephen Naumann, Donald Uffen, Univ Toronto, 416/424-3861

*Home Signaling System for the Deaf John Gresser, Purdue Univ, 317/494-1107

Sensory Feedback System for the Visually Impaired Daniel Tseng, Jason Mitchel, Chris Staufier, Karin Kindnesc, Northwestern Univ, Chicago, 708/491-5518

AccesScan: Making Appliances Accessible to the Handicapped Jesse Beeson, Erica Pinto, Univ Massachusetts, Lowell, 508/934-3359

Door-Opening Device for Wheelchair Users Mary Virginia Marsh, Kenneth Fields, Shaun Glasgow, Univ Alabama, Tuscaloosa, 205/348-1623

A Cursor Tracking Interface for the Handicapped: A Head-Controlled Joystick Aaron Samuelson, Ching-Yung Liu, Gregory Laufman, Cooper Union Sch Engineering, New York City, 212/353-4347

Accessible Sea Kayak Rudder System for Persons with Paraplegia Steven Reed, Univ Michigan, Ann Arbor, 313/936-7170

*Tool Modifications for a Dentist with a Cumulative Trauma Disorder Robert Feyen, Glenn Ashlock, Univ Michigan, Ann Arbor, 313/936-7170

Design for a Wheelchair Accessible Playground Swing Jan Sing, Kim Balentine, Caludia Truesdell, San Francisco St Univ, 415/338-2878

A Talking Scale for Industrial Packaging Jobs James Dattolo, Zhen Chang, Faisal Shajira, Wayne St Univ, Detroit, 313/577-3900

A Computer-Based Environmental Control System Richard Simpson, Glen Ashlock, Simon Levine, Univ Michigan, Ann Arbor, 313/936-7170

A Device for Aligning Below-Knee Prostheses Jordan Nicol, Simon Fraser Univ, Canada, 604/291-3756

The Innovative Classroom Maria Calitri, Univ Massachusetts, Lowell, 508/934-3330

A Body Powered Arm Orthosis for People with Muscular Dystrophy Rungun Ramanathan, Sean Stroud, Univ Delaware-Wilmington, 302/651-6833

Computer Controlled Wheelchair Dynamometer Sean Shimada, Brad Lawrence, Craig Ashford, Rory Cooper, Rick Robertson, Steven Albright, Univ Pittsburgh, 412/365-4850

*A Sandbagging Process that Accommodates the Mentally and Physically Disabled Paul Koeneman, Stephen Grupinski, Chin Chu, Univ Texas at Austin, 512/471-3030

A Foot-Powered Wheelchair Attachment for Use by Geriatric Patients Christopher Dansie, Univ Utah, Salt Lake City, 801/581-4163

Voice-Activated Ambulatory and Environment Control: A Conceptual Prototype Jeffrey Vogel, Univ Detroit Mercy, 313/993-3367

Occupational Rehabilitation Center William Todd Martin, C Tucker Cope, Matthew Morrison, Zufhair Hadi, Case Western Reserve Univ, 216/368-2941

**An Open Interface Telephone for Custom Applications Marc Todd, Univ Massachusetts, Lowell, 508/934-3341

Development of an Adaptive Algorithm for Real-Time Adjustment of User Interface Parameters Jeffrey Bishop, Univ Iowa, Iowa City, 319/335-6134

A Mailing Label Applicating Device for Use by Persons with Cerebral Palsy Daniel Stipe, North Carolina State Univ-Raleigh, 919/515-3785

The Curb Traversing Wheelchair J Anthony DelNegro, Gary March, Univ Delaware-Newark, 302/831-2008

Mobility Cart Sherri Koester, North Carolina State Univ-Raleigh, 991/515-3082

The WIL Chair: Wheelchair for Independent Living Judy Chen, Princeton Univ, 609/258-5154

Vector Controller of AC Motor for Power Wheelchair Won Nho, David Brienza, Univ Pittsburgh, 412/826-3138

Wheelchair Bumper Design Jennifer Lisauskas, Susan Moreira, Christopher O'Keefe, Worcester Polytech Inst, 508/831-5498

Wheelchair Roller Exerciser Troy Thompson, Brooke Kuffel, Marie Meier, David Smith, Worcester Polytech Inst, 508/831-5498

A Single Switch, Environmental Control, Audio Menu Selectable Remote Control Device for Severely Handicapped Children Frederick Darling, Univ Massachusetts, Lowell, 508/934-3330

AUGIE - A Portable Augmentative Speech Device for Non-Verbal People Sue Bravard, Western Washington Univ, Bellingham, 206/650-3506

*Winning Projects; **Honorable Mention Project

RESNA '95
Student Design Competition

In addition to these winning entries in this year's RESNA Student Design Competition, there were 27 other submitted projects. In my opinion, all of these applicants are winners because they have used their talents to better the lives of their fellow human beings. Judging the competition was extremely difficult because of the multitude of impressive projects. Our judges did an excellent job of assessing the entrants in light of our published design criteria and I am extremely proud to present to you this year's **TOP 5** and **Runner Up!** Please feel free to contact the sponsoring universities for additional information on these and other great projects.

I have promised to try to provide you, the reader, with the opportunity to link up with these budding young assistive technology designers. My greatest fear has always been that someone who would greatly benefit from one of the other projects would lose out because the information contained was not disseminated. To eliminate that possibility I have included a complete listing of the submitted projects with points of contact and telephone numbers. At least in this way if you are interested in a particular topic you can contact the author directly for more information.

Hopefully, by next year, we will have worked out a way to have all Student Design projects submitted under the normal paper application and review process. In this way they can be included with the regular Special Interest Group categories. Until we can publish them all, here's the entire submission list for this year's Student Design Competition. Enjoy and be sure to welcome our new talent to beautiful Vancouver!

David F. Law, Jr.
RESNA Student Design Competition Chair

DESIGN OF WORK JIGS TO ASSIST THE DISABLED IN SHELTERED WORKSHOPS IN THE PRODUCTION OF SAMPLE DISPLAY CHAINS

Robert Cavin, Irem Y. Tumer, Mark W. Foohey
Department of Mechanical Engineering
The University of Texas at Austin, Austin, Tx

ABSTRACT

This paper presents the development of work jigs to assist mentally and physically handicapped employees, or clients, at sheltered workshops in the assembly of interior decorating sample chip chains. The sample chain manufacturer, WilsonArt, hires sheltered workshops to assemble sample wafers, or chips, on a chain in a desired sequence. The goal of this project is to design jigs and/or process improvements to aid the mentally handicapped employees at sheltered workshops in assembling the chips on chains. The authors designed and developed two functional prototype work jigs and associated process improvements. These jigs facilitate the assembly of 236 sample chips onto a 22-inch contiguous ball chain by the mentally and physically handicapped clients at the sheltered workshop. Use of these jigs and the corresponding process recommendations assist the mentally and physically handicapped clients in achieving their tasks more effectively, while aiding sheltered workshops in achieving the production quality and volume requirements specified by WilsonArt.

BACKGROUND

Current practices for the treatment of the mentally and physically handicapped prescribe meaningful job activity as a means toward a more fulfilling life and societal integration [1]. To aid these efforts, many businesses employ sheltered workshops for appropriate aspects of their production processes. These sheltered workshops provide habilitation and income to the handicapped by serving as a contractor to businesses. VRC Industries of Austin, Texas, in affiliation with the Austin State School, is one such sheltered workshop, which through competitive bids, attracts various job activities for its mentally and physically handicapped clients [5]. Although many companies employ sheltered workshops for humanitarian reasons, this does not effect the business expectations and demands for production requirements. To gain contracts, VRC industries must meet the production and quality requirements specified by the companies.

One company actively involved in using sheltered workshops is WilsonArt, based in Temple, Texas. WilsonArt produces sample chips as shown in Figure 1 and assembles 236 different, individual chips onto a chain in a specific order. WilsonArt ships the individual chip supply boxes to sheltered workshops, such as the State School, and expects the chips themselves to be thoroughly inspected for defects and assembled defect-free on a chain.

STATEMENT OF THE PROBLEM

The authors accepted this project with the intention of helping VRC Industries achieve their production requirements while maintaining meaningful work activity for their clients. The project goal is to design jigs and/or processes to facilitate the production of WilsonArt sample chains by the mentally and physically handicapped clients. Jigs are used in sheltered workshops as a device to increase the productivity and accuracy of the workers [3]. Jigs are designed for mentally and physically disabled clients to guide movements, to provide cues, and to give physical assistance [4].

DESIGN

Engineers often use structured methodologies to guide the development of design solutions to problems such as in the sheltered workshop case. To address the problem of designing a suitable solution to the needs of sheltered workshop and its mentally handicapped clients, i.e., developing the work jigs to assist the mentally and physically handicapped in their daily tasks, the authors followed the recently developed Product Design and Development methodology by Ulrich and Eppinger [8]. Ulrich and Eppinger explain that structured methodologies make the design/decision process explicit, serve as a template to ensure consistent development activity, i.e., no forgotten issues, and that they are largely self-documenting, creating a future reference.

Upon understanding the problem and customer needs, the design team applied the Product Design and Development Methodology to the specific problem of assisting the sheltered workshop clients and staff in assembling sample chains. The general problem was identified and the project scope was defined using Quality Function Deployment (QFD) [8]. QFD charts reflect customer requirements and converts them into quantifiable engineering specifications. In the next stage of the development process, concepts were generated as a result of several brainstorming sessions. The concepts were then ranked by creating concept screening and selection matrices for each task. The remaining design alternatives were ranked by developing proof-of-concept prototypes. The

BEST COPY AVAILABLE

proof-of-concept prototypes were then presented to the customers at the sheltered workshop, leading to our final embodiment choices and preliminary functional prototypes (alpha prototypes).

To help concentrate on the important areas of the design specifications, we divided the process into three main tasks. The tasks follow the primary steps of chip assembly in the production line. We assumed the role of a chip progressing from the initial shipping boxes to its final assembly stage on a chain. At the first stage of production, the chip goes from the shipping boxes to the storage jigs. This initial task involves the removal of chips from shipping boxes, and delivery to the storage boxes. At the second stage, the chip goes from a storage jig to a client's hands. This second task involves the storage of the chips, enabling the start of the client interaction with the chips. The chips are distributed among the different areas, in the order required by WilsonArt. The chips are then stored in jigs. At the third stage of production, the chip goes from the client's hands to a sequencing jig. The sequencing jig is used to place all 236 chips in the correct order and orientation so that a chain can be strung through the chips for final assembly. Finally, the chain is strung through the assembled chips. To generate concepts the design team developed ideas based on experience and adaptations from literature [2, 7].

DEVELOPMENT

After a thorough analysis of the problem and generating concepts, the authors first built alpha prototypes to prove that the concepts were technically and functionally feasible. Alpha prototypes represent the first comprehensive, physical model of a design. Because analytical and partial models cannot fully capture all aspects of a design, designers often construct a second set of prototypes, namely beta prototypes, to implement improvements gained from insights learned from alpha prototypes. Beta prototypes are also often needed because the development process involves several iterations with customers and the alpha prototype may be the first opportunity for the customer to examine and to critique the first functioning prototypes.

Following a customer review and a basic understanding gained from alpha prototypes, the design team built beta prototypes for the storage jig and the sequencing jig. Figure 1 illustrates these beta prototypes.

The storage jig shown in Figure 1 combines five individual chip dispensing and storage units for use by one client. The storage jig is operated by a staff by turning an ergonomically designed handle. The handle rotates a roller with offset cams. The offset cams are placed underneath each storage unit and are used to feed one chip at a time, in the correct sequence. The staff turns the handle, the client removes a chip and hands it to the staff, who then places the chip in the sequencing jig. The staff pauses after each chip is fed out to provide the client with a clue to take the correct chip. This prevents the wrong chip from being placed in the sequence. The front of the jig is transparent to allow for visual inspection of the chip level in the jigs, as well as for visual stimulation of the mentally and physically handicapped clients. At the base of the front wall, a sweep is added to prevent multiple chips from feeding out. The back of the jig consists of a sliding door to allow hand loading of the chips into the storage jig. In addition, the back door is painted three colors to signal to the staff when chip levels are low.

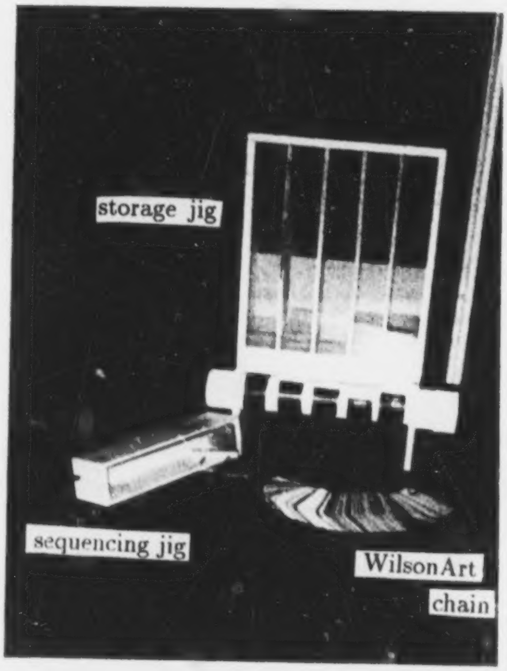


Figure 1: Beta Prototypes.

The sequencing jig shown in Figure 1 houses the chips during the assembly process. As the staff progress through the process, actuating the storage jigs and accepting chips from clients, they place the chips sequentially into this jig, hence its name. A hollow tube runs nearly the entire length of the sequencing jig, guiding chip insertion, preventing chip spillage, and aiding the eventual chain stringing operation. Once all 236 chips are assembled in the sequencing, the chain is dropped through the hollow tube and the ends are clasped, and the assembled product is delivered into return boxes.

DESIGN EVALUATION

Storage and sequencing jigs form the basis for the physical assembly process. The two jigs themselves meet many of the quality control specifications derived from our customers, such as preventing clients access to chip supplies and improved cueing techniques. The jigs provide the necessary cues and functions to help accomodate the job required by the mentally and physically handicapped. Note that it was important to maintain the client interaction with the chips, since client pay scale depends on interaction, while improving the WilsonArt chain production. Keeping the contract with WilsonArt heavily depends on the quality of the work produced by the sheltered workshop. The jigs and process currently used at the State School do not guarantee achieving the specified production rate. On the average, a completed defect-free chain must be produced every 2.5 minutes per building. This is infeasible with the current production system due to the final inspection operation. Based on these observations, the intended overall purpose of the jigs is to "mistake-proof" the assembly operations [6], thereby eliminating the need for final inspection. With the use of these new jigs, the client's current production rate is adequate to yield the desired production rate of 125 assembled, defect-free chains per day per building. In addition to eliminating most of the mistakes caused by the by the clients, the jigs assure that the clients maintain their required interaction level with the chips. Finally, the design provides for the possibility of clients gradually becoming more responsible in the production process, as their skills improve through the use of jigs.

DISCUSSION

This paper presents the development of work jigs for the assembly of interior decorating sample chains by the mentally and physically handicapped clients at the VRC Industries sheltered workshops. The authors designed and developed an improved production process and beta prototypes of the required work jigs. The system facilitates the assembly of 236 sample chips onto a 22-inch contiguous ball chain by the mentally and physically handicapped clients of the sheltered workshop. Use of the improved process recommendations and corresponding jigs aids in achieving the production quality and volume requirements specified by WilsonArt, and maintains the client interaction necessary for the clients to get paid. In addition, the jigs eliminate the need for the staff to constantly interfere in the production process in order to correct for client mistakes. Instructions on how to contruct the two work jigs and perform the suggested production process, as well as the beta prototypes have been provided for the State School. Note that it was requested that the designs be "low-tech" so that they could be easily manufactured at the State School facilities. The potential of these new jigs convinced WilsonArt to renew their contract with the sheltered workshop, allowing the mentally and physically handicapped clients to maintain their daily activity levels [5]. The State School is looking forward to building more jigs to be used by the staff and clients. Furthermore, WilsonArt has informed the workshop of their interest in distributing the new jig designs to other workshops.

ACKNOWLEDGEMENTS

We express our gratitude to VRC Industries and the Austin State School for providing such a worthwhile and inspiring project and assistance during the project; thanks Dr. Kristin L. Wood, Dr. Richard H. Crawford, and David Cutherell for providing guidance in applying the design methodology; thanks to Maria Vasquez for helping with client educational aspects.

REFERENCES

[1] G.T. Bellamy, R.H. Horner, and D.P. Inman. *Vocational Habilitation of Severely Retarded Adults: A Direct Service Technology*. University Press, Baltimore, 1979.

[2] N. Chironis. *Mechanism, Linkages, and Controls*. McGraw-Hill, Inc., New York, 1965.

[3] R.C. Conant and P. Sammartino. The utilization of jigs in training mentally retarded students. *55th Annual Internation Conference of the Council for Exceptional Children*, 1977.

[4] M.I. Davis and J.R. Fargher. *Rehabilitation Associate Training for Employed Staff: Production Methods*. Stout Vocational Institute, Menomone, WI, 1984.

[5] Mary Earls. *Personal conversation. February 17, 1995.* VRC Industries Sheltered Workshops. Austin, Tx.

[6] J. Gooch, M.L. George, and D.C. Montgomery. *America Can Compete*. The George Group Incorporated, Dallas, 1987.

[7] D. Macaulay. *The Way Things Work*. McGraw-Hill, Inc., Boston, 1988.

[8] K.T. Ulrich and S.D. Eppinger. *Product Design and Development*. McGraw-Hill, Inc., New York, 1994.

Irem Y. Tumer
Department of Mechanical Engineering
The University of Texas at Austin
ETC II 4.164A, Austin, Texas 78712-1063
(512) 471-7347, *irem@bertoni.me.utexas.edu*

733

TACTILE SENSING FOR PROSTHETIC ARMS

Warren C. D'Souza[✠,^], Henry O'Beirne[✠], Stephen Naumann[✠], Donald Uffen[^]
[✠]The Institute of Biomedical Engineering, University of Toronto, Toronto, ON, Canada
[^]Aastra Aerospace Incorporated, Toronto, ON, Canada

ABSTRACT

One area of research in the prosthetics field is the development of prosthetic arms to simulate the working of the human arm, and more specifically, the hand. Of prime importance in simulating the human hand accurately is the concept of tactile sensing. Tactile sensing, in the context of this project, describes the ability of a synthetic hand to perceive the objects with which it comes into contact as if it were a real hand.

If this feature can be incorporated into a prosthesis, it will enable the prosthetic hand to manipulate objects as delicate as an egg with the same ease as a bar of iron. The hand will apply more or less pressure to hold the object depending on the weight and fragility of it.

This paper describes the research and progress to date on the design of a child's prosthesis which incorporates tactile sensing using piezoelectric (PZT) ceramics.

BACKGROUND

Human beings without a disability have an inherent knowledge of how to handle different objects based on their past experiences and tactile feedback. They can detect such parameters as texture, shape, hardness, and weight. This ability provides vital feedback information for handling delicate objects firmly without damaging them.

For the person who has a disability, this is not an easy task. Though the person may know how to handle the object, the prosthetic hand does not. Since the hand does not give the person any feedback to let the person know if he/she is applying too much or too little pressure, the hand must operate independently to ensure the object does not slip from its grasp.

With that in mind, the child's prosthesis must have a simple control scheme. Current prostheses operate in only two modes, close and open. They work on the principle of exerting the motor to close the hand until stall current is reached. The system then assumes that maximum closure has been achieved and stops driving the motor. Since the stall current is fixed, so is the closure force.

Since it is preferable to firmly grasp the object being handled than risk dropping it, the stall current is adjusted to be quite high to handle heavier loads. This results in a large force which crushes more fragile objects.

STATEMENT OF THE PROBLEM

The purpose of this study is to determine if a prosthetic hand can be equipped with tactile sensing. The aim of this research is to enable an artificial hand to lift an object with a minimal amount of force such that both hard and fragile objects can be handled with equal proficiency.

RATIONALE

Incipient slip detection (1,2) has been attempted using such principles as detection of photoelastic effects (3), capacitive sensors (4,5), high frequency acoustic emissions (6), and piezoelectric sensors (7,8,9,10).

The authors began research into the possibility of incorporating automatic slip detection into a mechanical gripper using piezoelectric ceramics. This is accomplished by relying on the piezoelectric effect which converts mechanical energy into electrical energy.

When an object begins to slide across a piezoelectric material, mechanical vibrations result. These are translated into electrical signals which can be detected and interpreted as shown in Figure 1. By monitoring these signals it is possible to detect the presence of slip. These signals can then be sent to a controller to increase the grip force until sliding has stopped. It is further suggested that this can be done in a timely manner such that only a very minute amount of slippage occurs before the object is stopped. This amount should be so small as to be unnoticeable to the human eye.

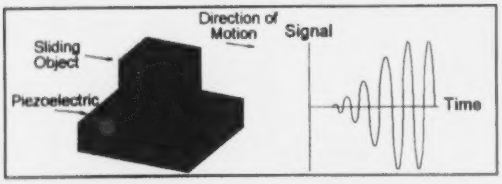


Figure 1: Piezoelectric Mechanism

DESIGN AND DEVELOPMENT

Piezoelectric Placement

In the case of the child prosthesis, the optimal location for the piezoceramics is in the fingertips themselves. To implement this scheme, the fingertips first had to be cut away to provide a flat surface upon which to mount the piezoelectric ceramics (See Figure 2). Subsequently, piezoceramics less than 1/8 of an inch thick were formed to the dimensions of the cutaway fingertip segments.

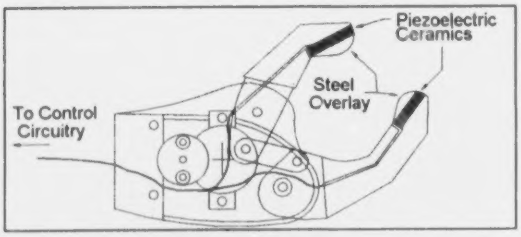


Figure 2: Modified Prosthesis

Interface and Backing

To protect the piezoceramic, an interface layer must be placed between it and the external environment. This protective layer must also form a good acoustic match with the piezoelectric to transmit the vibrations down to it. For the present time, it was decided to use steel as this layer. It satisfied both of the above two requirements and, additionally, was not too difficult to form into the shape of a fingertip. This last point is important because one of the key features in the design of a prosthesis is that it must be cosmetically appealing.

Presently, the researchers are also investigating the possibility of placing a backing material behind the piezoceramic, such as rubber, to dampen any vibrations originating in the arm which may be interpreted by the piezoceramic as a slip signal. However, at this time, it has not yet been implemented.

Signal Conditioning

To transmit the signals detected by the piezoceramics to the control circuitry, wires were soldered to each of the them, threaded through the fingers of the prosthesis and subsequently taken out through the hand assembly. These signals must first be amplified and filtered to achieve an appreciable signal level, and to isolate the appropriate frequency spectrum, respectively. The signals generated by the PZT are generally quite small (in the order of millivolts). This requires that they be increased to a level which can distinguish them from the noise floor. In addition, it was determined in the preliminary testing that the slip signal had most of its frequency content in the low end of the spectrum (below a few kilohertz). Therefore, a bandpass filtering circuit was designed to permit frequencies from 100Hz to 2.8kHz while attenuating everything else.

Once the signal passes this section, it is then converted to a digital value by an analog-to-digital converter. This is connected to a PC which performs the slip detection and controls the motor torque. This was done for ease of testing and prototyping. The final design would be implemented in discrete circuit technology.

Control System

Also changed for ease of preliminary testing was the motor. The existing prosthesis exerts a large amount of force upon closure. In order to do that, one must either use a powerful motor with a low gear ratio, or a smaller one with a high gear ratio. Since the motor must fit into the hand assembly, a small highly geared design is used. Unfortunately, this makes for a difficult control scheme for modifying the force.

The control system in the prototype is very simplistic. When the switch is closed, the software drives the high torque motor with a minimum voltage to close the fingers slowly. During this time, the position sensor, which changes with the position of the fingers, is monitored. When the fingers come into contact with the object to be held, the fingers slow to a stop. The software detects this lack of motion from the position sensor and enables slip detection. If the object begins to slip, the software increases the motor control voltage upon detection of a sufficient amplitude slip signal. When the object stops slipping, the slip signal drops below the threshold level, and the software slowly decreases the motor control voltage towards a minimum force level until slip is detected again. While this control scheme is easy to implement, it relies upon a linear relationship between the grip force and the control voltage. Thus, a gearbox cannot be used since it would introduce hysteresis and friction.

EVALUATION

Thus far, there have been some excellent qualitative results in the testing. The hand can grasp both heavy and fragile objects with a minimum amount of force. If the object is about to slide, the fingers increase their grasping force to hold more tightly.

DISCUSSION

Future Work

The next stage will be to implement a force control scheme using the small, highly geared motor design. With a gearbox, the force cannot be reduced simply by reducing the voltage to the motor. The motor must be backdriven to achieve the correct force. This will require a closed-loop force control scheme.

Another problem which will have to be solved is that of isolating the piezoceramics from vibrations occurring in the arm. The rubber backing may aid in this, but another possible solution may be to have a ceramic on the back of the hand which detects arm vibrations and subtracts this from the signal at the fingertips. This is a somewhat simplistic way of viewing the problem, and the concept needs further development.

Significance

The design and implementation of a prosthetic hand, which can independently determine the grasp force required to lift an object, will provide the user with the ability to handle hardy and fragile objects with equal ease. Since all the intelligence required to control the manipulator accurately will be encased in the controller design, no additional effort or stress will be required on the part of the user.

ACKNOWLEDGMENTS

Funding for this project is provided by the Natural Sciences and Engineering Research Council of Canada and Aastra Aerospace Inc.

REFERENCES

1. Kallhammer, J., Rebman, J. "A search for precursors of slip in robotic grasp." Intelligent Robots and Computer Vision: Fifth in a Series, Proceedings of SPIE 726 (1986): 329-337.
2. Cuttino, J., Huey, C., Taylor, T. "Tactile sensing of incipient slip." Proceedings of USA-Japan Symposium on Flexible Automation (1988): 547-555.
3. Eghtedari, F., Morgan, C. "A novel tactile sensor for robot applications." Robotica 7.4 (1989): 289-295.
4. Seekircher, J., Hoffmann, B. "Improved tactile sensors." IFAC Proceedings (1988): 317-322.
5. Zhu, F., Spronck, J.W. "A capacitive tactile sensor for shear and normal force measurements." Sensors and Actuators 31 (1992): 115-120.
6. Dornfield, D., Handy, C. "Slip detection using acoustic emission signal analysis." Proceedings of the 1987 IEEE International Conference on Robotics and Automation (1987): 1868-1875.
7. Howe, R., Cutkosky, M. "Sensing skin acceleration for slip and texture perception." Proceedings of the 1989 IEEE International Conference on Robotics and Automation (1989): 145-150.
8. Howe, R., Popp, N., Akella, P., Kao, I., Cutkosky, M. "Grasping, manipulation, and control with tactile sensing." Proceedings of the 1990 IEEE International Conference on Robotics and Automation (1990): 1258-1263.
9. Tremblay, M., Cutkosky, M. "Estimating friction using incipient slip sensing during a manipulation task." Proceedings of the 1993 IEEE International Conference on Robotics and Automation (1993): 9429-434.
10. Omata, S., Terunuma, Y. "New tactile sensor like the human hand and its applications." Sensors and Actuators 35 (1992) : 9-15.

Warren C. D'Souza
Aastra Aerospace Inc.
1685 Flint Road
Downsview, Ontario
M3J 2W8
Canada
(416) 736-7070 xt.270
(416) 736-7178 Fax
dsouza@ecf.utoronto.ca

HOME SIGNALING SYSTEM FOR THE DEAF

John F. Gresser
Electrical Engineering Technology Student
Purdue University, West Lafayette, IN U.S.A.

ABSTRACT

Audible signals are used in most households to signal an event. Doorbells, smoke detectors, telephones, and oven timers are a few examples of these signals. For the Deaf, an alternative must be found to alert them to these events. There exists several individual solutions for each device listed above. This paper will describe a system designed to accomadate all of these devices in a single package.

STATEMENT OF THE PROBLEM

As stated above, the audible signals used to signal an event occuring need to be converted to a visible signal to accomodate the needs of the Deaf. This can be a frustating and expensive problem to remedy. There are many solutions that address each signaling device individually using modular transmitting and receiving units. These solutions can involve replacement of the original device (i.e. doorbell) which is not always possible in an apartment situation. Also, buying separate transmitter/receiver pairs can be an expensive solution to this problem.

RATIONALE

To improve on the solutions listed in the previous section, several design alternatives were considered. The main concern was to eliminate the individual modules for each signaling device. To achieve this a central base unit was designed which "listened" for each alarm signal, analyzed the sound to determine which device was signaling, and then transmitted a unique pattern of flashes to remote light units placed around the home.

Another design consideration was to ensure portability between dwellings. To accomplish this, the system was designed to require no changes to the homes wiring system and no external hardware to install.

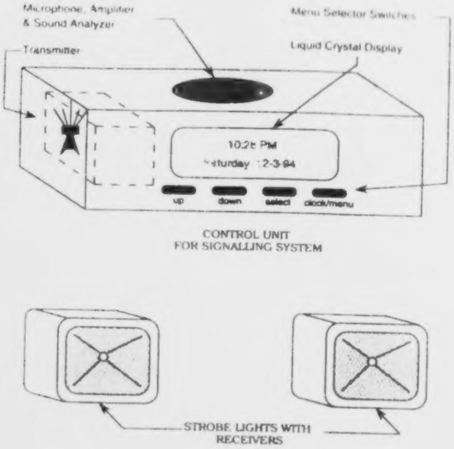
DESIGN

To implement the solution, the base unit was designed using a Signetics 552 microprocessor board as a controller. The base unit also contains an LCD display module, four menu buttons, a sound analyzer, and an FM transmitter. The remote light units will contain an FM receiver and a halogen light and will be powered from any 110 Vac household outlet.

DEVELOPMENT

Hardware

The prototype for this design is still in the development phase. The base unit will be roughly the size of a clock radio (10" x 6" x 4") and should be placed in a central location. The remote lights will be 5" x 5" x 5" and can be placed on a shelf or on the floor and pointed up to the ceiling. A diagram of the system is shown below.



Home Signaling System
for the Deaf
Final Package Design

If put into production, the unit cost should be between $50 and $75. The retail price would be less than two-thirds the cost of the alternative modular solution discussed earlier.

Software

The unit would be programmed by the user upon initial use. The microprocessor would guide the user through menus displayed on the LCD module. The pattern of flashes from the remote lights can also be programmed. A battery back-up system will be used to save the memory in case of power failure or the need to move the base unit.

EVALUATION

At the current phase of the project, all the individual circuits which have been completed are performing up to specifications.

DISCUSSION

The purpose of this project is to offer a cost effective means of providing visual alternatives to the auditory signalling systems found in most households. Any alternative solutions or improvements to this design would be welcomed by the author.

ACKNOWLEDGEMENTS

Purdue University provided the laboratory facilities and much of the reference material used to develop this project.

Thanks to Motorola for their assistance in donating the parts and documentation for the transmitter and receiver circuits

John F. Gresser
1155 Anthrop Dr. #5
West Lafayette, IN 47906
(317) 497-4543

TOOL MODIFICATIONS FOR A DENTIST WITH A CUMULATIVE TRAUMA DISORDER

Robert Feyen and Glen Ashlock
Rehabilitation Engineering Program
Department of Physical Medicine and Rehabilitation, University of Michigan Medical Center
Ann Arbor, Michigan

ABSTRACT

Cumulative trauma disorders (CTD's) of the hands and wrists are an increasingly reported cause of disability in many professions. Because dentists perform manual tasks which require highly precise and accurate motor control on a daily basis, these individuals are at high risk for disability due to CTD's. This paper describes tool modifications for a dentist with a CTD. Designed using ergonomic task analyses and able to withstand repeated sterilizations, these modifications have aided her successful return to work.

BACKGROUND

Cumulative trauma disorders (CTD's) are disorders of the muscles, tendons, nerves, and blood vessels that are caused, precipitated, or aggravated by repeated exertions or movements. These disorders are most frequently reported to affect the upper limbs and necks of workers, often with enough severity to cause impairments and disability (1). Within the medical and dental professions, CTD's of the hands and wrists have been identifed as the second leading cause of occupational injury (5).

In June of 1993, work began with a 33 year-old dentist (DW) who had been diagnosed with tendonitis and synovitis of the abductor and long extensor tendons of the thumb. Known as DeQuervain's disease, this CTD had required surgery and impaired her ability to the extent that she had not worked in seven months. To return to work in dentistry, DW required modifications of her dental hand tools.

LITERATURE REVIEW

Little has been published in the last twenty years specific to the ergonomic design of dental instruments. Khalil and Bell recommended "avoiding static loading of the muscles as well as awkward and unphysiologic positioning of the hand and wrist." They also specifically noted gross ulnar deviation and abduction of the thumb coupled with flexion of the distal phalanx as postures to avoid (4). Schwindt reported that most dental instruments currently in use were developed in the early 1900's to accommodate a standing dentist with an upright sitting patient. However, while the postures have since changed, the tools have not, placing "undue stress...on the operator's arm, wrist, and hand" (6). Johansson and Westling, while studying precise manipulation of small objects using the tips of the fingers and thumb, found that pinch force increased nonlinearly with the load force (3) while increased friction between the object and skin elicited lower pinch forces (2).

DESIGN CRITERIA

The American Dental Association and two dental manufacturers were not aware of any safety regulations specific to dental instruments, although one manufacturer stated that only FDA-approved materials were permitted for instruments designed for direct contact with a patient. To ensure that applicable regulations were met, the decision was made that any modified equipment used in direct patient contact would be manufactured by a dental supplier.

Sterilization procedures required that all equipment coming in contact with bodily fluids be autoclavable. Equipment was sterilized for 30 minutes at lunch break and after hours. Therefore, any materials used had to be heat-resistant to 270 degrees Fahrenheit and withstand repeated cycles. Space requirements in the autoclave required that any modified equipment fit inside a one square-foot plastic bag provided by the employer.

Between tool sterilizations, DW could see up to five patients; therefore, she required five sets of modified equipment. For a given patient, DW might use up to four cotton pliers, four mirrors, and four explorers (picks), and select from 17 other specialized tools. For dental extractions, DW typically selected from five different forceps. Given these numbers, modification or replacement costs per tool had to be reasonable for the expected benefits.

Since postural stresses due to flexion of the thumb's distal phalanx and abduction of the thumb placed DW at risk for DeQuervain's disease, a primary goal of the tool modifications was to discourage these actions. Secondary goals were to reduce the force requirements and eliminate prolonged static exertions for actions involving the affected tendons. However, modifications were not to interfere with or require changes in standard dental techniques.

TASK ANALYSIS

DW performed the following dental tasks with hand tools. Each task was evaluated for repeated and/or sustained static exertions, forceful exertions, and postural stresses.

Scaling, probing, carving, etc.: These tasks required fine motor control utilizing a precision pinch grip. The tools varied in handle shape and texture; typical diameters were 3/16". DW stated that the small handle diameters and the use of latex gloves led her to hold the tools tightly with the distal phalanx of the thumb in flexion to provide better tactile feedback. Typically, the thumb was also slightly adducted.

Manipulation with cotton pliers: The pliers were similar to a tweezers, requiring a pinch grip. The thumb was typically held in a neutral posture with flexion of the distal phalanx used to control the squeeze.

Drug injections and fluid withdrawal: This task utilized a syringe with a ring handle, held between the index and middle finger with the thumb placed in the ring with the distal phalanx flexed. With the syringe fully withdrawn, the thumb was grossly abducted and at the limits of DW's range of motion. She expressed significant discomfort with this task.

Cavity filling: Cavities were filled using an amalgam carrier, a device actuated when a 3/4" lever attached to the cylinder assembly was depressed by the thumb. The tool was held in a pulp pinch with the handle against the lateral surface of the index finger and the tip of the thumb on the lever. The thumb was abducted with the distal phalanx flexed.

Removal of teeth: Two different tools were used in removing teeth. One tool, the elevator, had a one-inch diameter handle with a wedge-shaped tip. The tip was inserted under the tooth between the roots and the tool rotated axially to raise the tooth out of its socket. This tool was held with a power grip with the thumb held straight along the tool's length. The second tool used was the extraction forceps, a specially designed pliers with which the dentist held the tooth. Extraction required a forceful and prolonged static exertion using a power grip while simultaneously twisting to lift the tooth free. DW's initial injury occurred during a two-and-a-half hour extraction.

TOOL MODIFICATIONS

Scalers, probes, carvers, etc.: DW sampled various handle configurations and selected a round handle of 5/8" diameter which decreased her distal phalanx flexion , improved tactile feedback, and reduced slippage. Thompson Dental Manufacturing (TDM) assisted in the final handle design (7). The solid 3/16" handles were replaced with 1/4" o.d. stainless tubing which reduced the tool weight and the handles were covered with a 3/16" thick autoclavable polymer material which further improved tactile sensitivity and grip friction. 152 tools were manufactured using this design.

Cotton pliers: The pliers were modified by attaching small stainless steel blocks to the handles which increased the index finger-to-thumb distance from 1/8" to 1/2" when the pliers were squeezed closed. This change required less fine motor control, was more comfortable to DW, and altered her squeezing action from distal phalanx flexion alone to thumb adduction with the distal phalanx held straight. Twenty pliers were modified.

Syringes: To reduce the thumb abduction and eliminate the need for distal phalanx flexion, the ring on the syringes was replaced with a t-bar found on another syringe style. The syringe could then be depressed using the lateral palmar surface of the thumb and hand. Withdrawal required two hands, but DW found that acceptable. Five syringes were modified.

Amalgam carriers: The effective lever length on these tools was extended from 3/4" to 1 5/8" with an increase in vertical height to approximately 1" from the handle. By more than doubling the moment arm for the thumb-actuated lever, actuation force at the tip of the lever was reduced by more than half. This also provided a horizontal surface on which to rest the thumb and encourage actuation with thumb adduction in which the distal phalanx was held straight rather than flexed. Ten modified amalgam carriers were constructed by a dental tool supplier.

Elevators: DW grasped the tool using thumb adduction to apply additional force. Since the grip force required to hold the tool without slippage was proportional to the torque applied, this grip style could induce high stresses in the thumb tendons. Addressed by replacing the cylindrical handled tools with commercially available elevators with T-bar handles, this effectively eliminated the thumb from the task and required less force to provide the same torque. Four elevators were ordered.

Extraction forceps: The prolonged static exertion required to hold the tooth during an extraction was targeted for reduction or elimination. Direct modifications to the forceps such as locking mechanisms were ruled out due to cost, bulk, and lack of manufacturing support (all extraction forceps are forged in Europe). Instead, a device was designed to allow foot control of the forceps pressure while keeping the hand free to manipulate the tool. Similar to a bicycle brake, a foot pedal (i.e., brake lever) was fastened by a five-foot cable and housing to a connector (i.e., brake calipers) to which all DW's forceps could be attached. The cable housing provided a flexible passage through which the cable could be drawn without slack. With the pedal depressed, the forceps were drawn closed; when released, springs in the connector and pedal assembly spread the forceps. To allow rapid forcep changes, the forceps slid into the connector and were held by two thumbscrews. A third thumbscrew at the connector adjusted the amount of forceps closure, necessary to prevent accidental weight shifts on the pedal from shattering the tooth being extracted.

Since the pedal was located away from the patient, only one pedal assembly was required and did not have to be sterilized. Aluminum was therefore used in the pedal to reduce weight and simplify fabrication. However, because the connector/cable assemblies had to be changed between patients, five cable sets were built with pedal attachment brackets to allow quick changeovers between patients.

The connector materials and pedal attachment brackets were stainless steel. The cable itself was stainless steel wire rope and the housing was heavy-walled teflon tubing. The cable was teflon-coated to eliminate abrasion between the metal rope braiding and the polymer housing. Teflon materials were selected for a low coefficient of friction, flexibility, and the ability to withstand sterilization temperatures. Low friction ensured the cable would slide without lubrication through the housing even when bent or coiled, while flexibility of the teflon tubing and wire rope allowed the cable sets to be coiled to meet the autoclave space requirements.

IMPLEMENTATION

Prototypes of all equipment designs were tested by DW and had to meet her approval prior to final manufacturing. Parts and manufacturing costs were under $4100. Before taking delivery of the equipment, DW was trained in their proper use and maintenance. Instruction sheets were provided as necessary and she was asked to call should any problems arise. DW returned to work on a full time basis in July, 1994. Followup calls revealed that she was pleased with the equipment, had no problems to report, and that her employer was considering the modified equipment for other employees. In February 1995, DW reported that she was still at work and had not experienced any further symptoms of DeQuervain's disease.

CONCLUSION

Static and forceful exertions as well as postural concerns can be identified in almost all hand-intensive tasks. In providing effective assistive technology for an individual with a CTD, task analyses help ensure that equipment designs avoid factors which may have caused the initial disability.

ACKNOWLEDGEMENTS

Support and technical assistance was provided by the American Dental Association, Grandville Sheet Metal, Hu-Freidy Manufacturing, Thompson Dental Manufacturing, University of Michigan Center for Ergonomics, the University of Michigan Dental School, and the University of Michigan Rehabilitation Engineering Program (UMREP).

Special thanks to Lincoln Jaros of UMREP for his early suggestions on the extraction equipment and to Chet and Ken at Grandville Sheet Metal for their invaluable advice on design-for-manufacturability with regards to stainless steels.

REFERENCES

1. Armstrong, T.J. "Ergonomics and cumulative trauma disorders of the hand and wrist," in Rehabilitation of the Hand, Hunter et al. C.V. Mosby, 1175-1191, 1990.
2. Johansson, R.S. & Westling, G. Signals in tactile afferents from the fingers eliciting adaptive motor responses during precision grip. Experimental Brain Research. 66, 141-154, 1987.
3. Johansson, R.S. & Westling, G. Programmed and triggered actions to rapid load changes during precision grip. Experimental Brain Research. 71, 59-71, 1988.
4. Khalil, T.M. & Bell, B.H. Ergonomic investigations in the design and use of hand instruments. Quintessence International. 3, 1-6, 1974.
5. Oberg, T. Ergonomic evaluation and construction of a reference workplace in dental hygiene: a case study. Journal of Dental Hygiene. 67, 262-276, 1993.
6. Schwindt, S.E. A review of hand instruments. Dental Hygiene. 50, 355-358, 1976.
7. Thompson Dental Manufacturing Co.
   1201 South 6th Street West
   Missoula, MT 59801

Robert Feyen
Rehabilitation Engineering Program
1C335 University of Michigan Hospital
Ann Arbor, MI 48109-0032
rfeyen@umich.edu

BEST COPY AVAILABLE

A Sandbagging Process that Accommodates the Mentally and Physically Disabled

Paul B. Koeneman, Stephen G. Grupinski, Chin S. Chu
University of Texas at Austin, Mechanical Engineering Department
Austin, TX

ABSTRACT

With the current trend of integrating persons with developmental disabilities into society as much as possible, many organizations are finding employment for the developmentally disabled with the intention of giving them a more independent life style. Some residents of the Austin State School earn money by producing sandbags. Their mental and physical disabilities make the labor difficult for them. A new sandbagging process and the associated hardware were designed to make the sandbagging operation easier for the workers. Their disabilities are accommodated by reducing the complexity and strenuousness of the tasks. A utility auger and a roller track table assist the workers in the new sandbag production process.

BACKGROUND

The Austin State School is operated by the State of Texas for the purpose of helping those with developmental disabilities. The current trend in the care for the developmentally disabled is to integrate them into society as much as possible[1]. One way of doing this is to have them earn money through employment. VRC Industries is a subsidiary of the Austin State School with this objective in mind. VRC employs residents of the Austin State School to produce products that require unskilled labor.

VRC Industries operates a sandbagging operation that employs six Austin State School residents and one trainer. The workers have mild or moderate physical and mental disabilities. The current process produces 600, fifty pound sandbags per ten hour work week.

The current process uses a volumetric hopper slightly higher than waist height to measure the sand and channel it into the bags. There are two hoppers operating simultaneously with one person shoveling sand into each one. Each hopper also has a person positioning the bags underneath it, operating the sliding gate, and dragging the filled sandbags away from the hopper. The fifth worker pulls the new bags off a stack, opens them, and helps position them under the hoppers. He moves back and forth between the hoppers. The sixth person seals the bags with a metal twist tie, using a rotary tying tool. Then he drags the sandbag to a pallet, and the trainer lifts the sandbag off the ground and places it on the pallet.

The purchaser of the sandbags has increased its demand from 600 to 800 sandbags per week. This means the production rate is insufficient to meet the full order. Also, the labor is very strenuous for the workers and trainer. There is a lot of bending and lifting in the operation. The primary goal of this project is to assist the workers with developmental disabilities and the trainer by reducing the level of exertion required by the process. The secondary goals are to increase the production rate and to decrease the mental complexity of the tasks.

Most of the design constraints came from the customer's wishes. The purpose of the sandbagging operation is not only to make money but also to employ the developmentally disabled. The new design was required to still employ six workers. This meant that complete automation was not an option. Quality is also a problem with the current process. The sandbags must be 50±5 pounds. The workers have difficulty remembering to level the sand in the hopper before releasing it into the bag. Also, by measuring the sand by volume, changes in the sand's density will change the mass of the sand dispensed. Since wet sand is twenty percent more dense than dry sand, this method of measurement does not meet the required tolerance.

METHODOLOGY

A product design methodology proposed by Ulrich and Eppinger[2] was used in this project. The first step was to observe the existing operation in action and conduct numerous interviews with the trainers and supervisors involved in the sandbagging operation in order to identify the customer's needs. The design team then translated the customer needs into engineering requirements and used Quality Functional Deployment to construct a House of Quality. The House of Quality helped show the interrelationships between requirements, determined the relative importance of the requirements, and established the target specifications.

Once the target specifications were determined, the concept generation phase began. The design team constructed a functional representation for the sandbagging process with the overall process being broken down to small, basic functions. The team

742

then combined discursive bias with brainstorming to generate solutions for each function. These solutions ranged from a vacuum system to a trenching machine. All the solution principles were combined in different ways to form concept variants. The concept variants were ranked against each other using criteria drawn from the target specifications. Two of the criteria that distinguished the concepts were the number of mental steps per task and the lifting force required from the workers. The three best concepts were presented to the customer, and the customer picked one.

Once a concept was selected, the detailed design began. Strength and stability analysis were used to determine appropriate dimensions for the structures. The electronics were designed to facilitate the convenient operation of the equipment. This was done by transferring some of the mental tasks from the worker to the electronics.

RESULTS

The final design uses a grain auger to elevate the sand and channel it into the bag. A scale is mounted in a roller track and measures the weight of the bag . A table supports the roller track at waist height. The sandbags sit on trays that roll on the track. The track guides the sandbag to the pallet where the bag is pulled off the track and onto the pallet.

The auger is an 11 foot long utility auger with a four inch diameter tube. As shown in Figure 1 the auger is supported by a stand with three casters. The angle of inclination of the auger is adjustable to give the auger a height range from four feet to eight feet. A one horsepower electric motor is mounted to the top end of the auger. A fill hopper is attached to the lower end of the auger. A two foot long section of four inch PVC pipe is mounted to the auger's outlet to channel the sand into the bag.

The scale is in the middle of the roller track, and consists of a box that sits on four springs. The roller track table is shown in Figure 2. The scale has rollers on top to allow the trays to slide over it. A microswitch is supported underneath the scale. A bolt protruding from the bottom of the scale activates the microswitch as the scale descends. The bolt is adjustable to allow for calibration.

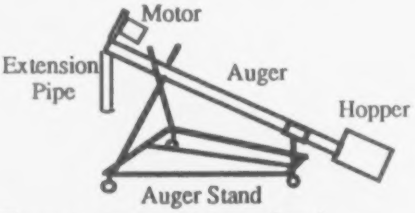


Figure 1. Auger and Auger Stand

The electronic controls were designed to simplify the operation for the operators. A start switch is mounted on the PVC pipe and starts the auger's motor. The switch is composed of a ring around the dispensing pipe and is activated by resting the hands on top of it and pressing down. A microswitch in the scale turns the motor off when the bag reaches the proper weight. An emergency stop switch is mounted on the front of the roller track.

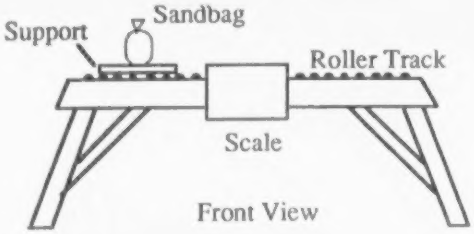


Figure 2. Roller Track Table

The new process still employs six students and one trainer. A schematic of the work site is shown in Figure 3. One worker sweeps the sand into the hopper. One worker standing at the mid-point of the track positions the bags around the PVC pipe and fills the bags. Two students stand on opposite sides of the bag filler and receive every other sandbag. They seal the sandbag with a twist tie and push the sandbag to the end of the track. One person is positioned at each end of the roller track to move the sandbags to the pallet. This is done by supporting the bag from underneath with both hands. The operator then leans back and pulls the bag into the body. The operator steps back from the track, turns, walks to the proper position on the pallet, and drops the sandbag.

S - Shoveling Operator
B - Bag Placing Operator
T - Tieing Operator
P - Pallet Loading Operator

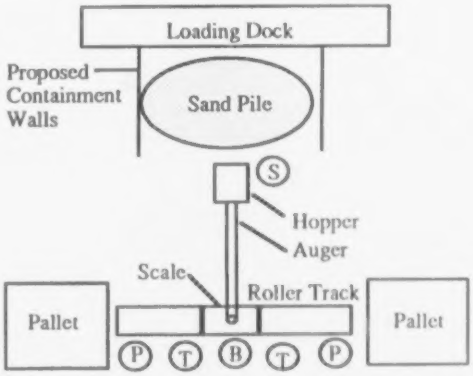


Figure 3. Top Down View of Work Site

Once the prototype was fabricated, it was tested at the work site. The process and equipment worked well, producing one sandbag every 40 seconds. Two problems were identified during the tests. First, the students occasionally allowed the bag to rest on the side of the roller track during filling. This caused the bag to overfill because not all the weight was on the scale. Second, the overflowing sand collected in the channels in which the scale slides. This caused the scale to jam.

A redesign resulted in guides placed on the roller track to prevent the track from taking any of the sand's weight during filling. Also, the gaps between the scale and the roller track were widened to allow sand to flow through rather than collect.

DISCUSSION

The old operation produced one sandbag per minute which results in 600 sandbags per week. The new operation produces one sandbag every 40 seconds which results in 900 sandbags per week. This is an increase in production rate of 50 percent. The demand of 800 bags per week can be met with this process.

The new process significantly decreases the level of exertion required. The old process required lifting a shovel full of sand above waist height. The new process ideally requires no lifting of sand. If the auger hopper is properly placed in the sand pile, the sand can just be swept into the hopper. Even if the hopper is improperly placed, the sand will only have to be lifted one foot off the ground as opposed to waist height. In the new process, the sandbag never has to be dragged on the ground. This eliminates a lot of bending from the operation. Bending is further reduced by elevating the tying operation to a comfortable working height. Perhaps most importantly, no one has to bend over and pick up the sandbag. The sandbag is already at the height it will be carried.

The new process is also safer than the old one. With less bending, there is less likelihood of a back injury. In addition, the trainer is no longer involved in the process. The trainer is free to supervise and direct.

CONCLUSION

With the rising popularity of integrating people with developmentally disabilities into active society, assistive technology is becoming increasingly important. New devices need to be designed to accommodate the disabilities of people capable of joining the work force. One such assistive device is described in this paper. The new hardware allows people with less abilities to join the sandbagging operation at VRC Industries.

The sandbagging process described in this paper uses an auger and roller track to reduce the amount of labor involved in producing sandbags and to increase the sandbag production rate. The labor was reduced by virtually eliminating all bending movements of the workers. The production rate increased from one bag every minute to one bag every 40 seconds. In addition, the operation was made safer by freeing the trainer to supervise rather than participate in the process.

ACKNOWLEDGMENTS

The funding for this project came a W.M. Keck Grant awarded to Dr. Kristin Wood, Associate Professor of Mechanical Engineering at the University of Texas at Austin.

Thanks to Dr. Wood, VRC Industries, and the Austin State School for their assistance in the completion of this project. In particular, Cesario Cadena, Bill Arteaga, and Sandra Bouldwin with VRC Industries were of great assistance in understanding the needs of the developmentally disabled. Also, thanks go to Nick Kiritis for his help in designing and fabricating the hardware.

REFERENCES

1. G.T. Bellamy, R.H. Horner, and D.P.Inman, "Vocational Habilitation of Severely Retarded Adults: A Direct Service Technology", University Press, Baltimore, 1979.

2. Ulrich, Karl T., and Eppinger, Steven D., *Product Design and Development*, McGraw-Hill, New York, 1995.

Paul B. Koeneman
University of Texas at Austin, ETC II 6.102
Austin, TX 78712-1063
(512)471-4772
koeneman@mail.utexas.edu

AN OPEN INTERFACE TELEPHONE FOR CUSTOM APPLICATIONS

Marc A.C. Todd
Assistive Technology Public Service Program
University of Massachusetts at Lowell, Electrical Engineering Department
Lowell, Ma U.S.A.

ABSTRACT

In today's world of advanced communications, the telephone provides the ability to connect with unlimited sources of information. For many physically disabled, the restrictive design of the telephone prohibits access to emergency assistance, family, friends, and business opportunities. These individuals require a new telephone design, flexible enough to allow custom interfacing for control of basic phone functions. This paper describes a prototype telephone designed specifically for a student at a local educational institution for the blind. The unit is dialed using a customized hand operated Morse code device. Other external features include customized headset, pickup, hangup, and error handling.

BACKGROUND

Jeff Watkins, a high school student, is blind with severe motor control disabilities and aspires to use the telephone unassisted. Jeff has excellent verbal skills and is particularly intelligent, making him the perfect candidate for employment. Two possible job interests as a receptionist have already surfaced for Jeff, the first at his present educational institution and the other at his family operated business. However, Jeff's motor skill limitations do not allow him to dial a standard telephone or pick up the handset without assistance. The challenge of working to meet Jeff's individual needs was accepted and a solution was developed.

DESIGN

The underlying problem of dialing with only gross motor function was considered initially. Morse code was chosen as the input language for two reasons; first, Jeff is already familiar with Morse code and second, Morse code is a simple method of communication. Such coding devices are flexible and easily adaptable to accept various inputs, for example, motion from a hand, knee, toe, head, finger, or some other distinct proficiency.

Using a series of five dots and/or dashes, all phone digits and keypad symbols are available to the user. The prototype unit accepts a series of Morse code sequences as input while all other interactive telephone functions, such as the receiver component and hangup/answer capabilities, are external and customized to the individual needs.

DEVELOPMENT

The telephone unit is comprised of two individual subsystems communicating between one another. The first is a micro controller based circuit that accepts Morse code as input. The second is a telephone circuit that communicates with the micro controller and performs all standard phone functions.

The micro controller is driven by a program developed to regulate the timing and feel of the customized hand operated actions. The algorithm polls the user input device and waits for an event to occur. When one of the Morse code controls is pressed, the program delays processing the dot or dash until the user releases. This functionality allows for fast or slow user input. The series of dots and/or dashes are stored until five events are recorded, at which time the algorithm converts the Morse code number to its respective dialing code. The special dialing code is sent to the telephone circuit.

The telephone circuit generates a tone corresponding to the dialing code received. This tone is sent via telephone lines to the local phone company who consequently dials that number. The telephone circuit also handles incoming calls, handset functions, and manual keypad dialing.

DISCUSSION

Many people with disabilities already have the skills, if not the mechanisms, to operate the switches needed to use Morse code but lack the tools to convert their talents, until now. The custom interface telephone with Morse code dialing is constructed for use with several input devices. Jeff operates a two stick customized hand operated Morse code unit appropriate for his limitations, however, any device using standard male phone jack connectors and toggling between short and open is operational. The pickup/hangup functionality is facilitated by a nine pin connection. Jeff uses a double throw, double pole switch embedded in a harness made specifically for his abilities. However, any device connecting the appropriate wires off of the nine pin port is suitable. The receiver outlet is a standard handset connection, allowing devices such as an everyday headset or a speakerphone extension to be compatible.

The custom interface telephone with Morse code dialing can be tailored to almost anyone who desires to use the phone. Once the twelve Morse code digits are known, the world is within reach.

ACKNOWLEDGMENTS

Funding for this project was provided by UMass Lowell, Assistive Technology Program.

Thanks to Professor Donn Clark, Professor Alan Rux, and Engineer Christopher Crotty.

Marc Todd
Student
Assistive Technology Public Service Program
University of Massachusetts at Lowell
One University Ave
Lowell, MA 01854
(508)922-6791
FAX (508)934-3027

Special Session
Current Trends in Wheelchair Propulsion Research

A new component to the 1995 Proceedings is the following section containing papers that have been presented as part of special sessions. A factor limiting the impact of special sessions has been the capability to transfer information beyond those individuals actually able to attend sessions. Through inclusion of papers in the Proceedings, improved documentation and more widespread dissemination will be possible. These papers are expected to adhere to the same standards as other papers published in the Proceedings.

WHEELCHAIR PROPULSION RESEARCH- PAST, PRESENT AND FUTURE

Janet H. Bednarczyk, RPT MPE, Royal Columbian Hospital,CANADA

ABSTRACT

The interaction between the user and his/her wheelchair is a long term interaction. The character of this interaction will affect many aspects of the user's life both in the short term as well as long term. The present paper reviews research which has been done in the area of wheelchair propulsion highlighting unresolved questions in this field of study. Recommendations for future research studies are discussed.

BACKROUND

Forward movement in wheelchair propulsion is the product of a repetitive, cyclical user-machine interaction. It is a mechancially ineffecient interaction as compared to other forms of human-machine interaction. Anyone engaged in research in the area of wheelchair propulsion must be sensitive to a number of factors which all may potentially affect output or forward movement of the user-chair system. These factors relate to the chair and its characteristics, the user and his/her characteristics and the match, or fit, between the two.

PURPOSE

The purpose of this paper is to critically review the research which has been done in the area of wheelchair propulsion, to outline the major questions which remain unresolved, and to make recommendations for future studies.

THE PAST

Early studies (1,2) focussed on the wheelchairs themselves and their characteristics. The goal of these studies was to try an determine what were the key mechanical properties of the wheelchair that could be altered to effect output. Later studies (3-5) focussed on the elite athletes and the fitness levels and wheeling abilities of the users. The goal of these studies was to improve athletic performance.

THE PRESENT

More recent studies (6-10) have attempted to determine which interactive factors between user and chair would affect output. There continues to be a strong emphasis on elite athletes and very little work is apparently being done of different user populations. There are very few centers conducting wheelchair propulsion research and there are even fewer multicenter, collaborative studies underway.

RESEARCH QUESTIONS

There are many questions which remain unresolved in this field of study. 1) The first area of controversy relates to how best to measure output in the user-chair system. Many authors have argued that kinematics and/or EMG are the measures of choice. There is stil some debate as to whether to use 2 dimensional or 3 dimensional kinematics. Other researchers argue that it is the energy consumed by the user which most accurately reflects wheeling performance and ultimately efficiency. Recently, two independent groups (Cooper and Niesing, 11,12) have developed the technology to measure force application directly on the wheel. This permits a more in depth analysis of the kinetics of propulsion (13) which is currently being coupled with kinematic and energetic.measurements in an attempt to get more detailed information about wheelchair propulsion. All of these methods require specialized, expensive laboratory equipment and expertise which place them out of reach of the majority of clinicians and users. There are very studies (14) which use non-invasive, low-tech methods which might be available to a clinician.

2) Other questions relate to the experimental design used in many research studies. Many of these have been performed in laboratories where the subjects have been required to perform on ergometers in wheelchair replicas

(15,16) which leaves many with questions about the relevance of these studies to real life wheeling situations. Even in the laboratory environment, there are unresolved questions about what kind of wheeling is the most important? Should one study accelerating or sprint (anaerobic) wheeling or is it preferable to study steady velocity (aerobic) wheeling. Some authors argue that anaerobic wheeling (17, 18) is more reflective of real life wheeling situations.

3) How important are the factors of fatigue and and variability of wheeling style in wheelchair propulsion? Some authors (19,20) have begun to examine this area.

4) One can ask how important are the factors of surface conditions for wheeling? These are factors such as wheeling on the level vs inclined or side-tilted surfaces and smooth vs rough surfaces. There is limited information on these factors (21-23) as they relate to output in wheelchair propulsion.

5) What factors related to the user are important to consider? Can the researcher use able bodied subjects and make suggestions about the disabled user as some authors would suggest (24,25)? If the users are disabled, how does the researcher quantify disability? There is some information available in this area (26,27) however this is limited to subjects with spinal cord injury. How does one chose which disabled group to study? There is limited information available on the capabilities of disabled groups (28,29) other than those with spinal cord injury and no comparative study between different disabled groups. It is also unclear how important the factors of user age or gender are in this field because there are such a small number of studies using young or female subjects (30,31).

RECOMMENDATIONS

There is a need to reach a concensus on the relative importance of these questions in the area of wheelchair propulsion.

Research teams need to work together, and in conjunction with clinicians, wheelchair manufacturers and users in order to design research studies which will have the greatest meaning in real life wheelchair propulsion. There is a need to determine basic, underlying principals of wheelchair propulsion which will have application to both clinicians and users in a variety of wheeling situations.

REFERENCES

1. Kauzlarich JJ, Bruning CC, Thacker JG. Wheelchair caster shimmey and turning resistance.J Rehab Res Dev 1985:22(3):25-41.
2. Peizer E, Wright D, Freiberger H. Bioengeineering methods of wheelchair evaluation. Bull of Prosth Res 1964:10:77-100.
3. Zwiren LD, Bar-Or O. Responses to exercise of paraplegics who differ in conditioning level. Med in Sci Sports 1975:7:94-98.
4. Lakomy HK, Campbell, MA, Williams C. Treadmill performance and selected physiological characteristics of wheelchair athletes. Brit J of Sport Med 1987:21:130-33.
5. Gass RM, Ginger JF, Lauback LL, Suprasayad AG. Metabolic and cardiopulmonary responses to wheelchair and bicycle ergometry. J of Appl Physiol 1979:46:1066-70.
6. Masse LC, Lamontagne M, O'Rain MD. Biomechanical analysis of wheelchair propulsion for various seating positions. J Rehabil Res Dev 1992:29(3):12-28.
7. Van der Woude LHV, Veeger HE, Rozendal RH, Sargent AJ. Optimum cycle frequencies in hand-rim wheelchair propulsion technique. Europ J Appl Physiol and Occ Physiol 1989: 58(6):652-35.
8. Hughes CJ,Weimar WH, Shet PN, Brubaker CE. Biomechanics of wheelchair propulsion as a function of seat position and user-to-chair interface. Arch Phys Med Rehab 1992:73:263-9.
9. Veeger HEJ, Van der Woude, LHV, Rozendal RH. Effect of handrim velocity on mechanical efficiency in wheelchair propulsion against constant power output. Med Sci Sports Exerc 1992:24(1):100-107.

10. Cooper RA. A systems approach to the modeling of racing wheelchair propulsion. J Rehabil Res Dev 1990:27(2):151-62.

11. Cooper, RA Watnabe KT, Ster JF. Smart Wheels: a device for studying wheelchair propulsion dynamics.. Proceed 13th Annnual IEEE/EMBS International conference, Orlando Fla. 1991:1817-18.

12. Niesing RF, Eijskoot F, Kranse R. Computer controlled wheelchair ergometer. Med Biol Eng Comput 1990:28(4):329-38.

13. Robertson RN, Cooper RA. Kinetic characteristics of wheelchair propulsion utilizing the Smart Wheel. Proceedings of the 17th Conference of the Amer Soc. Biomechanics Iowa, 1993:202-4.

14. Janssen TWJ van Oers AJM, Hollander AP, van der Woude LHV, Rozendal RH. Physical strain during activities of daily living in spinal cord injured subjects. In: Proceedings of the International Workshop on Wheelchair Research: Ergonomics of manual wheelchair propulsion, state of the art. Amsterdam: COMAC-BME 1991:113.

15. Veeger HEJ, van der Woude LHV, Rozendal RH. Within-cycle characteristics of the wheelchair push in sprinting on a wheelchair ergometer. Med Sci Sport Exerc 1991:23(2):264-71.

16. Jarvis S, Rolfe H. The use of an inertial dynamometer to explore the design of children's wheelchairs. Scand J Rehabil Med 1982:14:167-76.

17. Coutts KD, Strogyn Fl. Aerobic and anaerobic power of Canadian wheelchair track athletes. Med Sci Sport Exer 1987·19:62-5.

18. Lees A, Arthur S. An investigation into anaerobic performances of wheelchair athletes. Med Sci Sports Exerc 1987:31(11):1529-37.

19. Rodgers MM Gayle GW, Figoni SF. Biomechanics of wheelchair propulsion during fatigue. Archiv Phys Med Rehabil 1994:75:85-93.

20.Dallmeijer AJ, Kappe YJ, Veeger HEJ, Janssen TWJ, van der Woude LHV. Anaerobic power output and propulsion technique in spinal cord injured subjects during wheelchair ergometery.J RehabRes Devel 1994:2:120-128.

21. Brubaker CE, McClay IS. Determination and analysis for factors affecting wheelchair propulsion on lateral inclines. In: wheelchair mobility, Virginia Press, 1985:10-14.

22. Voight ED, Bahn CC. Metabolism and pulse rate in physically handicapped when propelling a wheelchair up an incline. Scan J Rehab Med. 1969;1:101-6.

23. Wolfe GA, Waters R, Hislop HJ. Influence of floor surface on the energy cost of wheelchair propulsion. Phys Ther 1977;57(5):1022-7.

24. Veeger HEJ, Lute EMC, Roeleveld K, van der Woude LHV. Difference in performance between trained and untrained subjects during a 30-s sprint test on a wheelchair ergometer. Eur J Appl Physiol 1992:64:158-66.

25. Brown DD, Knowlton RG, Hamill J. Schneider Tl. Hetzler RK. Physiological and biomechanical differences between wheelchair dependent and able-bodied subjects during wheelchair ergometery. Europ J Appl Physiol and Occ Physiol 1990:60(3):179-82.

26. Bednarczyk, JH, Sanderson. Comparison of functional and medical assessment in the classification of persons with spinal cord injury. J Rehabil Res Dev 1993:30(4):405-11.

27. Maynard FR, Karunas R. Relating neurological recovery and functional recovery after acute SCI. J Am Parap Soc 1992:15(2):130.

28. Lehman JF, Warren CG, Halar E, Stonegridge JB, DeLateur BJ. Wheelchair propulsion in the quadriplegic patient. Archiv Phys Med Rehabil 1974:55:183-6.

29. O"Connell DG, Barnart R, Parks L. Muscular endurance and wheelchair propulsion in children with cerebral palsy and myelmeningocele. Archiv Phys Med Rehabil 1992:73:709-11.

30. Bednarczyk JH, Sanderson DJ. Kinematics of wheelchair propulsion in adults and children with spinal cord injury. Archiv Phys Med Rehabil 1994:75:1327-1334.

31. Knowlton RG, Fitzgerald PI, Sedlock DA. The mechanical efficiency of wheelchair dependent women during wheelchair ergometry. Canad J Appl Sport Sci 1981:6:187-90.

Janet Bednarczyk,
Royal Columbian Hospital
260 Sherbrook St.
New Westminister, B.C. V3G 3M2

BIOMECHANICS OF WHEELCHAIR PROPULSION: RELATIONSHIP TO INJURY

RN Robertson, RA Cooper, ML Boninger, G Ensminger, SD Shimada
HUMAN ENGINEERING RESEARCH LABORATORIES
Div. Phys. Med. & Rehab., Dept. Orthopaedic Surgery, University of Pittsburgh Medical Center
Depts. RST, ME & BME, University of Pittsburgh, Research Services, Highland Dr. VAMC

ABSTRACT

Wheelchair users using everyday chairs experience a high incidence of injuries, particularly to the shoulder and wrist. It is important to understand the stresses being borne across upper extremity joint structures in order to model injury mechanisms. Our laboratory has found a number of important features of upper extremity joint kinetics: considerable differences observed between experienced and non-experienced users, large joint forces observed at the shoulder, even during recovery, while some users apply extremely high vertical and medial components of force to the pushrim. This information with further assessment of joint kinetics will allow the clinician to implement appropriate intervention strategies and the engineer to modify wheelchair design to effectively reduce stresses borne by upper extremity joints.

INTRODUCTION

Although there have been many studies on wheelchair propulsion biomechanics, few of these studies have aided the medical practitioner with wheelchair prescription and modification or have provided the means for changing potentially harmful stroke mechanics. The majority of articles and text which describe appropriate wheelchair prescription rely on anthropomorphic measurements to determine such variables as seat height, depth, wheel size and position. A change in any of these variables will affect biomechanics, thus may affect injury incidence, while no studies to date have attempted to investigate the relationship between wheelchair biomechanics and injury.

INJURY TO WHEELCHAIR USERS

The prevalence of upper extremity injury in the spinal cord injured (SCI) population using wheelchairs has been shown to be high. Often as high as 51% experiencing shoulder problems [1], while 30% suffer persistent, chronic shoulder pain during transfers [2], along with a prevalence of Carpal Tunnel Syndrome [3,4]. Sie et al. found that 51% of the individuals with quadriplegia reported upper extremity pain (UE), most commonly at the shoulder [5]. The investigators stated that this frequent and demanding use of the UE's among SCI patients may lead to pain and injury resulting in severely impaired functional independence.

KINEMATICS

A number of researchers have investigated the kinematics of wheelchair propulsion, which describe the motion of the various body segments, but few have related this to potential injury. Flexion and extension of the joints of the upper extremity have been described as being the main motions produced [6] during 2 general phases: drive and recovery [6,7]. Van der Woude et al. measured the effect on pushing parameters (cycle frequency, push time, recovery time and push angle) during two different workload strategies of changing speed and slope on a treadmill [8]. They generally found that push time decreased with increasing speed but not with slope, while recovery time remained constant at higher speeds, but decreased with increasing slope.

KINETICS

The kinetics of wheelchair propulsion has not been studied extensively. One of the largest drawbacks is the lack of adequate instrumentation to accurately measure the forces exerted by the individual while pushing a wheelchair. Brauer and Hertig measured static torque produced at the pushrim of a stationary wheelchair [9]. They concluded that the amount of torque produced by the user at the push rim varies with grip location, handedness, grip strength, and/or how well the wheelchair fits the anthropometric measurements of each subject.

Veeger et al. compared trained and untrained subjects on a dynamometer during a 30-second sprint test [10]. The estimated pushrim forces were defined as Ftot (the resultant of the 3 orthogonal forces), Fm (the effective force on the pushrim, the tangential force), FEF (fraction of effective force

752

determined as the ratio between the tangential force and the total force). Differences in estimated force application existed between both groups which in part was attributed to the use of the elbow flexors. However, FEF was not significantly different. The researchers concluded that the low FEF may be the result of non-optimal wheelchair dimensions, an ineffective propulsion technique or the need for a large friction force between hand and rim.

RESULTS FROM OUR STUDIES

Robertson et al. [11,12] utilizing the Smart^{Wheel} (a force sensing wheel) showed differences in propulsion biomechanics between wheelchair users and non-wheelchair users, illustrated in figure 1. The Smart^{Wheel} was designed to allow the clinician to evaluate the net forces and moments acting on the joints of the upper extremity during wheelchair propulsion. Figure 1 illustrates the pushrim forces (F-resultant, Fx-horizontal, Fy-vertical, Ft-tangential, Fr-radial) plotted as a function hand location (90 degrees represents top dead center). The results from this study showed that experienced wheelchair users produced pushrim forces that were lower in magnitude, while maintaining lower peaks for longer periods of time. An impact spike was observed at hand contact, which indicated a rapid force loading at the beginning of the stroke. Tangential forces applied to the push rim were also shown to be more optimally produced by wheelchair users.

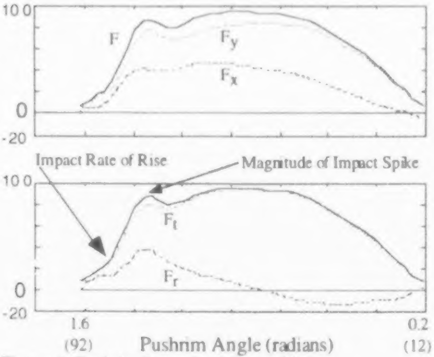


Figure 1. Pushrim forces by joint position.

Joint Moments: Figure 2 illustrates the peak shoulder joint kinetics for the 3 groups of users (F-NWCU-female non-wheelchair user, M-NWCU-male non-wheelchair user, M-WCU-male wheelchair user) and the time during the propulsion stroke when the peak Fy occurred. The shoulder showed the largest forces and moments.

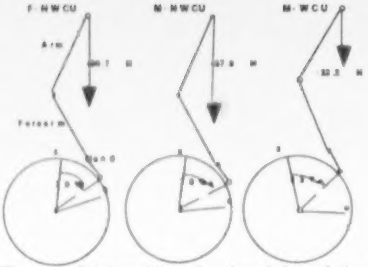


Figure 2. Joint positions, hand-pushrim relationship, and peak shoulder vertical reaction force Fy.

In a preliminary study, Robertson et al. showed that joint moments at the shoulder peaked approximately 75% of the way through the propulsion cycle (see figure 3), while considerable variability was observed across speeds and between subjects [12].

Figure 3 illustrates a plot of each joint moment as a function of joint position. Each curve represents the mean of 20 strokes for each group. The experienced vs. non-experienced groups were considerably different from each other.

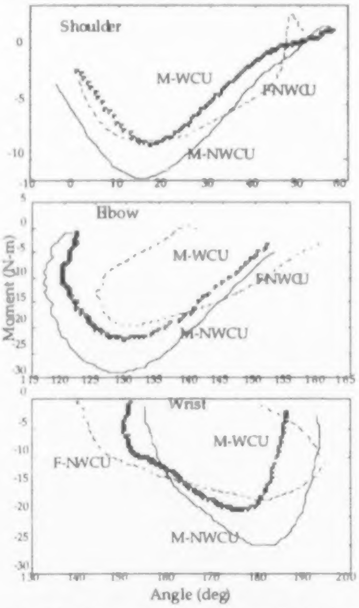


Figure 3. Joint moments plotted against joint angle

Figure 4 illustrates a plot of the Fy-vertical (A) and Mz-moment net reaction forces (B), at each of the 3 upper extremity joints. This data showed that variable net joint forces and moments were observed across subjects and joints during wheelchair propulsion. All subjects exhibited relatively large forces and moments at the shoulder

BEST COPY AVAILABLE

joint, notably, a large vertical component. This produces a force at the shoulder which has a tendency to drive the humeral head into the acromial shelf; a possible mechanism traumatizing shoulder joint structures. The rapid rises in force observed at the beginning of the propulsion phase, particularly in the vertical direction may cause an overtaxing of joint structures. This may be detrimental to wrist joint structures, as this is the point in time when some individuals have a tendency to have a non-neutral wrist position. This has been implicated as a possible cause for producing injuries in the carpal canal. More extensive analyses need to be performed on a larger number of subjects before definitive statements concerning injury mechanisms can be made or appropriate intervention strategies implemented.

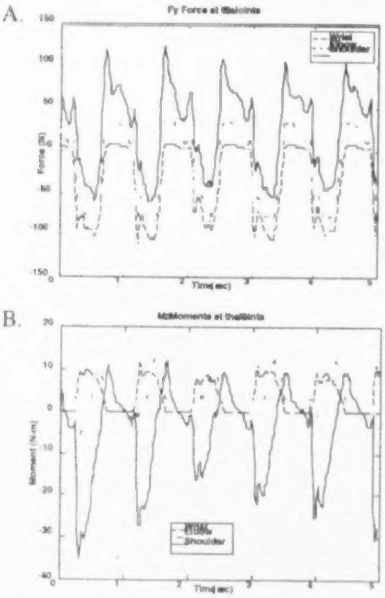


Figure 4. Net joint forces (Fy), A, and net joint moments (Mz), B, at all 3 joints for subject 1.

CONCLUSIONS

We have identified various aspects of upper extremity joint kinetics during wheelchair propulsion which may induce trauma to the joint structures. Several refinements of the segment models and further assessment of joint kinetics for larger numbers of subjects must be completed before a comprehensive profile of upper extremity joint kinetics can be made. This information will allow the clinician to implement appropriate intervention strategies and the engineer to modify wheelchair design to effectively reduce stresses borne by upper extremity joints.

REFERENCES

[1] Nichols, PJ et al. (1979). Wheelchair user's shoulder? *Scand. J. of Rehab. Med.*, 11(1), 29-32.

[2] Bayley, JC et al. (1987). The weight bearing shoulder. The impingement syndrome in paraplegics. *J. Bone Joint Surg.* 69, 676-678.

[3] Alijure, J et al. (1985). Carpal tunnel syndrome in paraplegic patients. *Paraplegia,* 23, 182-186.

[4] Gellman, H et al. (1988). Carpal tunnel syndrome in paraplegic patients. *J. Bone Joint. Surg. [Am]* 70, 517-519.

[5] Sie, I et al. (1992). Upper extremity pain in the post rehabilitation spinal cord patient. *Arch. Phys. Med. Rehab.* 73, 44-48.

[6] Davis, R et al. (1988). The competitive wheelchair stroke. *NSCA Journal*, 10(3), 4-10.

[7] Sanderson, D J & Sommer III, HJ (1989). Kinematic features of wheelchair propulsion. *J. of Biomechanics*, 18(6), 423-429.

[8] Van der Woude, et al. (1988). Manual wheelchair propulsion: Effects of power output on physiology and technique, *Med. Sci. in Sp. and Ex.*, 20(1), 70-78.

[9] Brauer, RL & Hertig, BA (1981). Torque generation on wheelchair handrims. *Proceedings 1981 Biomechanics Symposium*, ASME/ASCE Mechanics Conference, Colorado, pp. 113-116.

[10] Veeger, HEJ et al. (1992.) Differences in performance between trained and untrained subjects during a 30-s sprint test in a wheelchair ergometer. *Euro. J. Appl. Physio.* 64, 158-164.

[11] Robertson, RN, & Cooper, RA (1993). Kinetic characteristics of wheelchair propulsion utilizing the SmartWheel. *Proceedings 17th Annual Meeting of the American Society of Biomechanics*, Iowa City, Iowa, pp. 202-203.

[12] Robertson, RN et al. (1994). Upper extremity net joint forces and moments during wheelchair propulsion. *Proceedings 17th Annual RESNA Conference*, Nashville, TN, pp. 155-157.

ACKNOWLEDGEMENTS

Partial funding for this research was provided by the U.S. Department of Veterans Affairs Rehabilitation Research & Development Services (Project #B686-RA) through the Edward Hines Jr. D.V.A. Hospital and the U.S. Department of Education, Rehabilitation Services Administration (H129E00005).

BEST COPY AVAILAB

EVALUATION OF EXERCISE CAPACITIES OF WHEELCHAIR USERS

K.D. Coutts, Department of Human Kinetics & Allan McGavin Sports
Medicine Centre, University of British Columbia, Vancouver, B.C., Canada

ABSTRACT

A battery of three laboratory wheelchair exercise tests was developed to evaluate the fitness of wheelchair athletes. Tests included a 10 second sprint test, a 30 second anaerobic power test, and determination of the peak oxygen uptake while wheeling using a progressive increase in power output. A sample of 15 subjects provide a general indication of the fitness of wheelchair athletes. The highest wheelchair sprint speed was 8.46 m/s (30.5 km/h). In the 30 second anaerobic test, male basketball players had lower peak powers and total work than track athletes. The track athletes had higher peak oxygen uptakes (45 ml/kg/min) compared to the basketball players (35 ml/kg/min).

INTRODUCTION

The determination of peak oxygen uptake during wheelchair propulsion is the most common wheelchair exercise test reported in the literature. This test quantifys the aerobic power of the subject and therefore the capacity for endurance activity, but does not evaluate the abilities of the subject for short duration exercise bouts. The development of a battery of wheelchair exercise tests which attempt to span the range of muscular efforts found in sports competitions as well as daily activities is desirable for evaluating manual wheelchair users. The purpose of this paper is to describe three wheelchair exercise tests that have been used in a program to evaluate wheelchair athletes, and to provide a summary of the results of this testing as an indication of the performance abilities of these athletes.

METHODS

15 athletes (3 female,12 male) were involved in the testing program. The athletes had all qualified to compete at the national and international level. The purposes and results of the tests are discussed with each athlete in relation to their training programs and goals. An instrumented set of rollers was used to provide a means of setting and monitoring the speed and power output of the athlete while wheeling in their own wheelchairs.

Three exercise tests were administered to each subject in the following sequence after allowing the athlete to perform a normal warm-up. A 10 second sprint test requiring the athlete to accelerate from a stationary start and wheel as fast as possible for 10 seconds was the first test.. The second test was administered after at least a five minute recovery period and involved a 30 second all-out effort against added resistance with the athlete starting at or near maximal speed. The added resistance is set so that the athlete's peak speed is 20-30% lower than the peak speed achieved on the 10 second, low resistance sprint test. The peak power output during a 5 second interval, the total work in 30 seconds, and the fatigue index which is the percentage decrease in power output from the peak value to the power output in the last 5 seconds were determined. The last wheelchair exercise test was for the determination of the subject's peak oxygen uptake. A continuous protocol involving speed and resistance increases was used to attain peak oxygen uptake values. a power output of about 50 watts during the first minute of exercise with increases of 10-20 watts each minute.

RESULTS

Table 1 presents some of the characteristics of the 15 athletes and their

TABLE 1 - 10 SECOND SPRINT TEST DATA

Subj	Gender	Class	Sport	Peak speed WC(m/s)	Rim(m/s)	Peak accel	Distance (m/s/s)
1	F	1B	Swim	2.06	1.79	1.53	19
2	F	4	Bball	2.68	2.37	3.09	25
3	F	4	Track	3.42	1.48	2.40	29
4	M	4	Bball	4.02	3.76	3.10	35
5	M	4	Bball	4.02	3.61	8.70	36
6	M	3	Bball	4.12	3.58	5.35	37
7	M	3	Bball	3.92	3.46	4.26	31
8	M	2	Track	6.56	3.13	5.96	50
9	M	5(Amp)	Track	5.74	2.78	3.47	42
10	M	5(Amp)	Track	8.46	3.88	13.51	59
11	M	4	Track	6.56	3.18	13.20	53
12	M	4(Polio)	Track	6.70	3.60	7.96	50
13	M	5(Amp)	Track	6.43	3.16	6.30	50
14	M	3	Track	5.18	2.63	11.76	37
15	M	4	Track	5.18	2.53	3.28	42

TABLE 2 - 30 SECOND ANAEROBIC POWER TEST

Subj	Peak power (w)	(w/kg)	Total work (J)	Fatigue index (%)
1	23	0.4	644	13
2	68	1.1	1886	20
3	85	1.7	2255	26
4	126	1.4	3461	15
5	139	2.0	3833	20
6	122	2.0	3440	10
7	142	1.9	3776	25
8	158	2.7	4378	13
9	170	3.1	4881	11
10	223	4.5	6205	16
11	164	2.3	4651	13
12	247	4.4	6983	10
13	134	2.2	3906	2
14	193	3.0	5523	8
15	164	2.6	4738	6

TABLE 3 - PEAK OXYGEN UPTAKE TEST

Subj	Oxygen uptake (l/min)	(ml/kg/min)	Heart rate (bts/min)	Vent-BTPS (l/min
1	0.68	11.5	117	24
2	2.01	33.3	173	86
3	1.89	39.8	180	68
4	2.76	30.7	174	129
5	2.58	37.0	190	95
6	2.08	34.7	198	84
7	2.83	38.4	178	111
8	2.90	46.8	178	99
9	2.58	47.5	185	85
10	3.35	67.2	178	189
11	3.76	51.7	182	153
12	3.18	55.0	188	116
13	2.61	47.8	182	97
14	2.86	44.4	183	121
15	2.14	34.5	182	84

best performances on the 10 second sprint test. The class of the athletes was determined using the International Stoke Mandeville Games Federation classification system for track athletes (amputees were considered as Class 5). The results on the 30 second anaerobic power test for the same athletes are reported in Table 2, and Table 3 provides their results on the peak oxygen uptake test.

DISCUSSION

The ten second sprint test provides a measure of the athlete's ability to accelerate a wheelchair against a light resistance and is long enough for the athlete to attain maximal speed. The determination of peak push rim speed was considered a valuable measurement in this test since it reflects the peak speed of the hands during propulsive movements with the peak wheelchair speed being a function of the hand speed and the ratio of the wheel to push rim radius which is analogous to the gear ratio in a bicycle or car. Thus the sprint test provides a measure of the limit of the individual's hand speed in low resistance propulsive efforts which, while dependent on technique, may also reflect basic neuromuscular properties of the locomotor muscles.

The 30 second anaerobic power test has been shown to be related to performance in short distance track events (100 - 400m) in a group of wheelchair athletes. The top sprinter in the present study (Subj. #10) exhibited one of the highest scores on this test which supports this relationship. The relatively large number of male basketball and track athletes allows some comparison between these groups. The track athletes generally had higher peak power and total work scores than the basketball players, and a lower fatigue index. All of the track athletes trained for and competed in races of 1500m or longer which would help explain their lower fatigue index. energy into the measured output values.

The determination of peak oxygen uptake during wheelchair exercise is basically a test of the power of the wheelchair user's aerobic energy supply system which, in a limited number of studies involving a heterogeneous sample (athletes and non-athletes) of wheelchair users, has shown a reasonable relationship to actual endurance related wheelchair locomotor performance.

The peak oxygen uptake values reported in Table 3 are in general agreement with other studies of wheelchair athletes. The relationship between peak oxygen uptake and endurance performance in a more homogeneous athletic sample has not been clearly established. While subject #15, with the lowest peak oxygen uptake, had the poorest 1500m time at the 1988 Paralympics, subject #8, with only an average value of 46.8 ml/kg/min, had the fastest 1500m time at the 1988 Paralymics and won the Oita International Marathon in the same year. The unusally high peak oxygen uptake of 67.2 ml/kg/min for subject #10, while reflecting a good aerobic energy system also reflects his low body mass due to lower limb amputation. In general a peak oxygen uptake of 45 ml/kg/min or higher appears to be a characteristic of male, class 2-5, wheelchair track athletes who compete at the international level, while male basketball players exhibit a lower value of about 35 ml/kg/min.

The use of a battery of three tests (i.e. 10 second sprint, 30 second power, and peak oxygen uptake provide a reasonable sample across the range of possible combinations of intensities and durations. The relative lack of normative data and well established relationships between test results and actual wheelchair performance limits the interpretability of the test results, and further accumulation of data using more standardized tests is needed in order to remedy this limitation in wheelchair exercise testing.

The University of British Columbia,
The School of Human Kinetics,
210-6081 University Blvd.,
Vancouver, B.C. Canada V6T 1Z1

PHYSICAL CAPACITY AND PHYSICAL STRAIN IN PERSONS WITH QUADRIPLEGIA

Annet J. Dallmeijer, Maria T.E. Hopman* and Luc H.V. van der Woude
Faculty of Human Movement Sciences, Vrije Universiteit Amsterdam, The Netherlands
* Department of Physiology, Catholic University of Nijmegen, The Netherlands.

ABSTRACT

Physical capacity (PC) and physical strain (PS) during standardized ADL were investigated in 25 persons with quadriplegia (QP). Maximal aerobic power output (POmax), maximal oxygen uptake (VO2peak) and maximal isometric force (Fiso) was determined on a stationary wheelchair ergometer. Physical strain was described as the maximal heart rate response expressed as percentage of the heart rate reserve. Among PC parameters significant relationships were found (r=0.64 to 0.83). Lesion level, completeness of the lesion and sport activity were the most important determinants predicting PC. Significant inverse relationships were found between PS of all ADL and parameters of PC (r=-0.41 to -0.85). To predict PS, parameters of PC were found to be significant predictors, whereas no relationship was found between PS and lesion level. It is concluded that the level of PC in QP is highly important to reduce strain during daily life.

BACKGROUND

Persons with a spinal cord injury (SCI) have an extremely low physical capacity (PC), especially those with a cervical spinal cord injury. A limited muscle mass and a disturbed sympathetic innervation are the main factors limiting the PC in persons with quadriplegia (QP) (1). In a previous study (2) it was found that SCI encounter high levels of physical strain (PS) in activities of daily living (ADL). It was observed that QP encounter significantly higher levels of PS than paraplegics. Additionally, an inverse relationship between PC and PS during standardized ADL was observed. The high PS in ADL can lead to the development of a sedentary lifestyle, probably resulting in a further decrease of PC (3). An increase of health risks like cardiovascular diseases and musculoskeletal disorders can be the consequence. The inverse relationship between PC and PS implies that an increase in PC may result in a decrease of PS during ADL. Therefore, it is suggested that a higher level of physical capacity is associated with an improved health status (4). Until now, the relationship between PC and PS was only established in a SCI population, a mixed group of persons with paraplegia and QP, whereas no data are available with respect to QP exclusively.

RESEARCH QUESTIONS

The purpose of this study was 1) to quantify PC and PS during standardized ADL in a group of persons with quadriplegia, 2) to determine determinants predicting PC and PS and 3) to examine the relationship between parameters for PC and PS.

METHOD

PC and PS during standardized ADL was investigated cross-sectionally in 25 persons with quadriplegia (mean age: 32.8 (sd: 10.6) years), with lesion levels ranging from C4 to C8. Ten subjects (all male of whom 4 had incomplete lesions) participated in any form of sport activity, whereas 15 subjects (12 male with 1 incomplete lesion and 3 female with 2 incomplete lesions) were sedentary QP. Time since injury ranged from 0.5 to 32.3 years (mean: 6.1; sd: 6.6).

PC was measured as maximal power output (POmax), maximal oxygen uptake (VO2peak) and maximal isometric arm force (Fiso) during a maximal aerobic exercise test and a maximal force test on a stationary, individually adjustable, wheelchair ergometer (5).

To investigate PS the heart rate response was recorded with a portable heart rate monitor (Polar Sporttester) during ascending a ramp, passing a door, washing hands and submaximal wheelchair propulsion (simulation of propelling a ramp of 0.5° during 3 minutes). To estimate PS the maximal heart rate response evoked during the task was expressed as percentage of the heart rate reserve (HRR = difference between maximal heart rate and heart rate at rest) (6).

Pearson correlations were calculated to establish relationships among parameters for PC and between PC and PS. Regression analysis, using Fiso and Pomax as independent variables was used to predict Pomax and VO2peak. To predict parameters of PC and PS regression analysis was applied, using lesion level, hours sport per week, age, time since lesion and completeness of the lesion as independent variables. Level of significance was $p < 0.05$.

RESULTS

Mean values for POmax, VO2peak and Fiso were 19.4 Watt (sd: 13.0), 0.82 $l.min^{-1}$ (sd: 0.40) and 112 N (sd: 66.8) for the total group, respectively. Significant positive relationships were found between Fiso and POmax (r=0.81), between Fiso and VO2peak (r=0.64) and between POmax and VO2peak (r=0.83).

Correlation coefficients between PC parameters and lesion level were not significant for the total group. After excluding persons with incomplete lesions correlation coefficients of 0.74, 0.61 and 0.79 were found for lesion level with POmax, VO2peak and Fiso, respectively. Hours sport per week was found to correlate significantly with POmax (r=0.67) and VO2peak (r=0.74) for the whole group, whereas no correlation was found between Fiso and hours sport per week. Exclusion of persons with incomplete lesions resulted in slightly lower correlation coefficients.

Multiple regression analysis showed that 69% of the variance (r^2) of POmax can be explained by lesion level, sport activity and completeness of the lesion. 64% of the variance in VO2peak can be explained by sport activity and completeness of the lesion. Only 37% of the variance of Fiso was accounted for by lesion level and sport activity. Regression analysis excluding persons with incomplete lesions showed slightly higher percentages: 74% for POmax and 67% for VO2peak, in which lesion level and sport activity were the significant determinants. After excluding subjects with incomplete lesions Fiso showed a remarkably higher percentage of explained variance (62%), which was predicted by lesion level only. It appeared that age and time since injury were no significant predictors of PC parameters in this cross-sectional study.

Average PS for the whole group was for ascending a ramp 49.0 %HRR (sd: 17.3), for passing a door 44.6 %HRR (sd: 17.8), for washing hands 44.5 %HRR (sd: 15.7), and 66.4 %HRR (sd: 18.6) for submaximal wheelchair exercise.

Correlation coefficients calculated between PS during ascending a ramp, passing a door and washing hands and parameters for PC were all significant and ranged from r=-0.41 (washing hands and POmax) to r=-0.58 (passing a door and POmax). For submaximal wheelchair propulsion a stronger relationship was observed; ranging from r=-0.62 (VO2peak) to r=-0.85 (POmax). PS demonstrated an inverse relationship with PC during all tasks.

No relationship was found between PS during the tasks and lesion level. Hours sport per week showed only a significant relationship with PS of washing hands (r=-0.51) and during wheelchair propulsion (r=-0.51). When considering subjects with complete lesions only, a significant inverse relationship of PS with age was found for ascending a ramp (r=-0.72) and passing a door (r=-0.54).

Additional regression analysis, using PC parameters, lesion level, hours sport per week, age and time since injury to predict PS, showed no improvements in these relationships. Thus, PC parameters were found to be the most important variables to predict PS during ADL tasks.

DISCUSSION

The relatively low values for POmax, VO2peak and Fiso reflect the extremely low PC in persons with QP and are in agreement with previous results (2,3). PS during standardized ADL was found to be notably high in QP. Values are higher than previous results in paraplegics and comparable to previous values found for QP (2). This underlines the assumption that QP encounter higher levels of PS in daily life than paraplegics and may therefore be more susceptible for health problems.

The positive relationship between POmax, VO2peak and Fiso, is in agreement with a previous study in a SCI population (7), although a slightly lower correlation coefficient was found in the present study. However, the regression equation predicting POmax from Fiso differed from the SCI population (7); at the same Fiso a much lower POmax was delivered in the current study (regression coefficients for the current study: 0.16, for Janssen et al (7): 0.34). The same trend was found for Fiso predicting VO2peak (regression coefficients for the current study: 3.37, for Janssen et al (7): 6.52). A high dependency on the very limited amount of muscle mass for performing exercise in QP might be an explanation for this finding. The regression equation for POmax predicting VO2peak was comparable to the equation found for SCI (7). These results suggest a different relationship between Fiso, and POmax and VO2peak in QP compared to paraplegics. Further research is needed to establish proper relationships. However, it seems not reasonable to restrict testing and evaluation of PC in QP to only one parameter of PC, as has been suggested for the SCI population (7). Force strength, sprint power and aerobic exercise performance appear to be useful variables to investigate in this respect.

The positive relationship between VO2peak and POmax, and hours sport per week, indicates the positive effect of sport activity. However, bias due to the cross-sectional character of this study should be taken into account; better performing persons are more likely to participate in sport activities. To establish the effect of sport activity or regular exercise programs, longitudinal research is inevitable.

After exclusion of subjects with incomplete lesions a higher positive relationship was observed between lesion level and PC parameters. This finding might be expected, since the amount of muscle mass will be the limiting factor in exercise performance of QP (1).

The inverse relationship between PC and PS, although less strong compared to previous results (2), demonstrates the advantage of a high PC in reducing PS during daily life. Regression analysis showed that PC was the most important variable in predicting PS during daily life. Lesion level was not a significant variable to predict PS, also after exclusion of persons with incomplete lesions. This strongly supports the assumption that increasing PC in QP is of utmost importance. Training programs or an active lifestyle can reduce PS in daily life, may consequently enlarge mobility and increase the quality of life, irrespective of lesion level.

It is concluded that QP have an extremely low PC and that they encounter high levels of PS during daily life. The inverse relationship between PC and PS during ADL, the positive influence of sport activity on PC and the fact that PC is the most important predictor of PS supports the assumption that increasing PC is of utmost importance for QP. Longitudinal research is required to establish proper relationships between activity level and PC and PS during ADL.

REFERENCES

1. Figoni, S.F. Exercise responses and quadriplegia. *Med. Sci. Sports Exerc.* 25, 433-441, 1993.

2. Janssen, T.W.J., C.A.J.M. van Oers, H.E.J. Veeger, A.P. Hollander, L.H.V. van der Woude, R.H. Rozendal. Relationship between physical capacity and physical strain during standardized ADL tasks in men with spinal cord injuries. *Paraplegia* 32, 844-859, 1994.

3. Hoffman, M.D. Cardio respiratory fitness and training in quadriplegics and paraplegics. *Sports Med.* 3, 312-330, 1986.

4. Haskell, W.L. Health consequences of physical activity: understanding and challenges regarding dose-response. *Med. Sci. Sports Exerc.* 26, 649-660, 1994.

5. Niesing, R.F., Eijskoot, F., Kranse, R., den Oude, A.H., Storm, J., Veeger, H.E.J., van der Woude, L.H.V., Snijders, C.J. A computer controlled wheelchair ergometer. *Med & Biol Engin & Comput* 28, 329-338, 1990.

6. Karvonen, M., Kentala, E., Mustala, O. The effects of training on heart rate. A longitudinal study. *Am. Med. Exper. Biol. Fenn.* 35, 307-315, 1957.

7. Janssen, T.W.J., C.A.J.M. van Oers, A.P. Hollander, H.E.J. Veeger, L.H.V. van der Woude. Isometric strength, sprint power, and aerobic power in individuals with a spinal cord injury. *Med. Sci. Sports Exerc.* 25, 863-870, 1993.

ACKNOWLEDGEMENTS

Support for this project was provided by the Prevention Fund, The Netherlands, The Netherlands Federation for Adapted Sports, The Netherlands, and the Rehabilitation Centre Amsterdam, The Netherlands. The authors gratefully thank M.H.M. Mertens and M.H. Kal for their participation in the data collection.

Annet J. Dallmeijer
Faculty of Human Movement Sciences
Vrije Universiteit Amsterdam
van der Boechorststraat 7
1081 BT Amsterdam
The Netherlands

MANUAL WHEELCHAIR PROPULSION CENTER OF PRESSURE

RA Cooper, RN Robertson, ML Boninger, DP VanSickle and G Ensminger

HUMAN ENGINEERING RESEARCH LABORATORIES
Depts. Rehab. Sci. & Tech, Mechanical Engineering and Bioengineering, University of Pittsburgh
Div. Phys. Med. & Rehab., Dept. Orthopaedic Surgery, University of Pittsburgh Medical Center,
Research Service, Highland Drive Veterans Affairs Medical Center

ABSTRACT

This paper focuses on methods for determining location of the pushrim center of pressure during wheelchair propulsion. Wheelchair propulsion is accomplished by the bilateral simultaneous repetitive motion of the upper extremities. The pushrim is grasped or struck and pushed downward and forward, in turn, rotating the wheels. The center of pressure (COP) is the location of a virtual resultant vector acting on the pusrim. The action forces are under motor control of the upper extremities. A flexible hand model which assumes that the hand is locked to the pushrim and the quasi-static wrist moment accounts for the moment seen by the pushrim. Most previous investigations have assumed that the COP is coincident with the MP joint of the first finger. The COP measurements using a flexible hand model agrees closely with the path of the MP joint of the first digit.

CENTER OF PRESSURE ANALYSIS

The SMART$^{\text{Wheel}}$ is a pushrim which is capable of measuring forces and moments applied to it. The center of pressure (COP) is the location of a virtual resultant vector acting of the SMART$^{\text{Wheel}}$. The action forces are under motor control of the upper extremities. If the interface between the hand and pushrim is treated as a ball and socket joint, then the hand only exerts force on the pushrim. If the hand/pushrim interface is treated as an elastic element, then the hand can transfer forces and moments to the pushrim. In the former case, the COP must lie on the pushrim within the surface covered by the hand. This is not guaranteed if the hand can impart a moment. By developing a marker system which identifies the surface of the hand in relation to the pushrim, the appropriate hand interface model can be determined. A system of four to six markers on the hand can be used to determine orientation of the hand with respect to the pushrim, hand curvature (e.g., a rectangular spline could be used), supination/pronation of the hand (i.e., by examining the orientation of the hand plane with respect to the forearm/arm plane), and flexion/extension of the hand (i.e., by examining the orientation of the hand plane with respect to the forearm segment). The location of the COP as determined by the SMART$^{\text{Wheel}}$ reaction forces and the location of the hand determined through the kinematic skin markers will lead to information regarding the appropriate interface. If the COP lies outside the surface of the hand in contact with the rim, then an elastic element model is necessary. If the COP lies within the plane of the hand a ball and socket model may be sufficient.

Center of Pressure Theoretical Development

The COP location in the sagittal plane can be determined from the sagittal forces (F_x, F_y) and moment about the wheelchair axle (M_z). The forces Fx and Fy in the world coordinate frame are the components along the x (horizontal) and y (vertical) axes, respectively, of the resultant F. Similarly, Fr and Ft in the wheel reference frame are components along the wheel spokes and tangential to the pushrim, respectively, of the resultant F. The wheel coordinate frame can be viewed as a rotating version of the world coordinate frame. This information can be exploited to estimate the COP. The resultant F is a function of Fx and Fy or Fr and Ft as shown in equation (1).

$$F^2 = F_x^2 + F_y^2 = F_r^2 + F_t^2 \qquad (1)$$

The angle F makes with respect to Fx is governed by the relationships

$$\cos\theta_1 = \frac{F_x}{F} \qquad \sin\theta_1 = \frac{F_y}{F} \qquad (2)$$

and the angle F makes with respect to Fr is governed by a similar set of equations

$$\cos\theta_2 = \frac{F_r}{F} \qquad \sin\theta_2 = \frac{F_t}{F} \qquad (3)$$

Unit basis vectors for the xy and rt coordinate systems can be defined from θ_1 and θ_2,

$$\hat{F}_{xy} = \cos\theta_1 \hat{i}_1 + \sin\theta_1 \hat{j}_1 \quad \hat{F}_{rt} = \cos\theta_2 \hat{i}_2 + \sin\theta_2 \hat{j}_2$$

respectively.

$$\hat{F}_{xy} = \cos\theta_1 \hat{i}_1 + \sin\theta_1 \hat{j}_1 \quad \hat{F}_{rt} = \cos\theta_2 \hat{i}_2 + \sin\theta_2 \hat{j}_2$$

The angle between the xy and the rt coordinate systems completely specifies the COP location.

$$\cos\varphi = \cos\theta_{1-2} = \hat{F}_{xy} \bullet \hat{F}_{rt} = \frac{F_r F_x + F_t F_y}{F^2}$$

The COP is (φ, R), where R is the radius of the pushrim, and is determined by taking the arc-cosine of equation (5), and using information based upon the kinematics of the stroke to determine which quadrant the hand is located, because, equation (6) yields two solutions 180-degrees transposed. The hand-pushrim interface was modeled as a flexible coupling. The SMART$^{\text{Wheel}}$ measures the moment about the axle (M_Z) which consists of two components: the moment applied by the hand; and the torque produced from the product of the tangetial force times the pushrim radius.

Center of Pressure

$$M_z = M_{hz} + F_t R \qquad (6)$$

The moment applied by the hand (M_{hz}) and the tangential force (F_t) are not measured directly with the SMART^{Wheel}. However, both are required to determine the COP explicitly using equation (5).

$$F_t = \frac{M_z - M_{hz}}{R} \qquad (7)$$

$$F_r^2 = F^2 - F_t^2 = \left(F^2 - \frac{M_z^2}{R^2}\right) + \left(\frac{2M_z M_{hz} - M_{hz}^2}{R^2}\right)$$

$$= \tilde{F}_r^2 + \left(\frac{2M_z M_{hz} - M_{hz}^2}{R^2}\right)$$

The COP location is dependent upon the actual values of Ft and Fr as shown in equation (7). Sagittal plane kinetic and kinematic data must be used to estimate COP. The forces and moments about the wrist can be summed at each sample instant to yield the contribution of the propulsion forces and moments to wrist moments and forces, equation (8), see **fig. 1**.

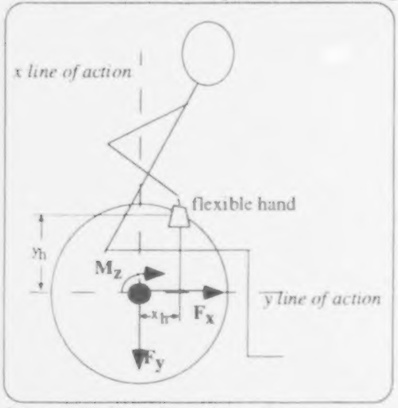


Fig. 1 Schematic for calculation of quasi-static wrist moment.

$$F_{hx} = -F_x \qquad F_{hy} = -F_y$$

$$M_{hz} + M_z + y_h F_x - x_h F_y = 0$$

With an estimate of the wrist moment available, the pushrim tangential (Ft) and radial (Fr) forces and sagittal plane COP can be readily calculated, see equations (1), (5) and (7). The COP is restricted to be on the pushrim to reduce the number of possible solutions.

COP MEASUREMENT

Experimental Protocol

Three subjects (two male and one female) gave written informed consent and voluntarily participated in this study. All subjects were experienced manual wheelchair users (two have thoracic level spinal cord injuries, and one has multiple sclerosis). All subjects had been using a wheelchair for at least three years prior to the study. Subjects wore a black leather fingerless glove during the experiment. A Quickie GPV wheelchair with 0.41 m seat depth and 0.41 m seat width was configured with a SMART^{Wheel} attached to its right side. The wheel camber for both rear wheels was set to zero. Reflective markers were placed on the acromion, olecranon, ulnar stylion, radial stylion, metacarpo-phalangeal joint of the first and fourth fingers. The wheelchair with each subject, in-turn, were aligned and secured over the rollers of computer numerically controlled (CNC) dynamometer [7]. The calibration of the SMART^{Wheel} was verified using a 4.4 Kg mass. Each subject pushed the wheelchair on the dynamometer for five (5) minutes to become accomodated. Each subject propelled the wheelchair at 2 miles per hour for two minutes with dynamometer power set to 7 Watts. Pushrim forces were recorded for the last fifteen seconds of each test. Pushrim force and moment data were collected at 240 Hz with a digital SMART^{Wheel}, whereas kinematic data were collected at 60 Hz with a PEAK5 3 camera motion analysis system. Kinematic and kinetic data collection were synchronized via a computer generated synchronization pulse to the SMART^{Wheel} and GenLoc camera system. Cameras were placed in the frontal plane rotated upwards 45 degrees from the transverse plane, in-line with the SMART^{Wheel} axle and perpendicular to the sagittal plane, and at axle height midway between the sagittal and medial-lateral planes. Data were reviewed immediately post testing to ensure proper collection.

Results from COP Model

Centers of pressure on the pushrim during the propulsion phase of manual wheelchair propulsion were analyzed using two models. The quasi-static wrist moment can affect the center of pressure location, therefore, centers of pressure were calculated for each subject using a flexible hand model as described in equation (7), see **fig. 2a**. Videographic techniques were used to track the path of the metacarpal-phalangeal (MP) joint of the first finger during the entire the propulsion cycle over four strokes. A direct linear transformation was used to determine the projection of the 3D motion onto the sagittal plane. The propulsion phase of the kinematic data were determined by parsing the section of the kinematic data corresponding to the initial deflection of the axial moment curve (Mz) from the baseline to the time the axial moment curve returned to baseline. The angle of contact with the pushrim for each subject's MP joint were plotted from the parsed MP joint kinematics, see **fig. 2b**. The hand may be in contact with the pushrim and applying a propulsion moment even when the MP joint appears not to be in contact. This situation indicates that force is being transmitted to the pushrim either through another portion of the fingers or through the palmer surface of the hand.

DISCUSSION

Hand moments may exist because the hand is capable of grasping the pushrim during propulsion. Hence

Center of Pressure

analysis of COP is more complex than it is for force plates used in gait analysis. The propulsion phase of a manual wheelchair stroke occurs in the first and second quadrants. Contact begins in the second quadrant, behind the shoulder joint center, and continues forward into the first quadrant. The propulsion phase begins with the arms hyperextended and abducted and ends with the arms forward flexed and adducted. This motion pattern results in the radial force being small upon contact, during stroke transition from rearward oriented arms to anterior palcement of the arms, and at release [2-5]. All of the COP estimates exhibit instability when low forces are applied. This is a characteristic of COP measurement common to most force sensing systems [1]. The instability lies in the dependence upon ratios of forces to determine COP position. When forces are small, their ratios can vary greatly due to sources of error of the same order of magnitude.

Most previous investigations have assumed that the COP is coincident with the MP joint of the first finger [6]. This may be a reasonable assumption, as the COP measurements using equation (7) agree closely with the path of the MP joint of the first digit, see **figs. 2a,b** respectively. The COP can not be accurately calculated when the one of the forces or moments required by equation (7) is missing. The availability of only propulsion torque (Mz) to most laboratories has spawned the practice of using the MP joint as coincident with the COP. Our results indicate that for gross motion studies this appears adequate. However, the location of the COP within the hand may provide important information related to propulsion abnormalities and is valuable in reducing initial condition errors for joint moment calculations during the propulsion phase of wheelchair mobility. The results of this study indicate that the COP does change position within the hand.

REFERENCES

1. M.F. Bobbert, and H.C. Schambardt, "Accuracy of determining the point of force application with piezoelectric force plates," *J. Biomechanics*, Vol. 23, No. 7, pp. 705-710, 1990.
2. R.A. Cooper , R.N. Robertson , and D.P. VanSickle, "A Recursive Back Propagation Algorithm for Computing Net Muscle Moments and Net Joint Forces," *in Proc. 16th Annual RESNA Conference*, Las Vegas, NV, 1993, pp. 277-279.
3. R.A. Cooper, K.T. Asato, R.N. Robertson, and J.F. Ster, "2-dimensional kinetic analysis of manual wheelchair propulsion with an improved Smart$^{\text{Wheel}}$," *in Proc. IEEE-EMBS 14th International Conference*, Paris, France, 1992, vol. 14, no. 4, pp. 1544-1545.
4. R.N. Robertson , R.A. Cooper , G.J. Ensminger, and K.J. Stewart, "Upper Extremity Net Joint Forces and Moments During Wheelchair Propulsion," *Proc. 17th Ann. RESNA Conf.*, Nashville, TN, 1994, pp. 155-157.
5. R.N. Robertson, and R.A. Cooper, "Kinetic characteristics of wheelchair propulsion utilizing the Smart$^{\text{Wheel}}$," *in Proc. 17th Ann. Meeting of the Am. Society of Biomechanics*, Iowa City, Iowa, 1993, pp. 202-203.
6. M.M. Rodgers, G.W. Gayle, S.F. Figoni, M. Kobayashi, J. Lieh, and R.M. Glaser, "Biomechanics of wheelchair propulsion during fatigue," *Arch. Phys. Med. Rehab.*, vol. 75, pp. 85-93, 1994.
7. A.J. Vosse, R.A. Cooper, and B. Dhaliwal, "Computer Control of a Wheelchair Dynamometer," *in Proc. RESNA 13th Annual Conference*, Washington, D.C., June, 1990, pp.59-60.

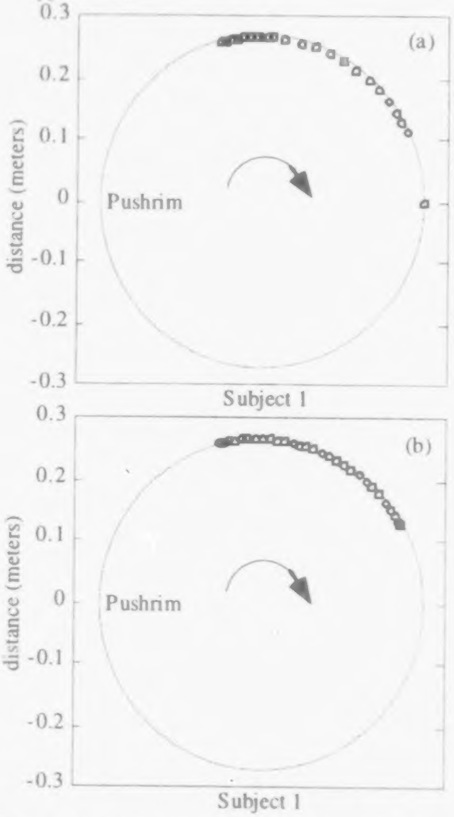


Fig. 2 (a) COP with flexible hand model, (b) path of MP joint.

ACKNOWLEDGEMENT

This research was partially supported by a US Department of Veterans Affairs, Rehabilitation Research and Development Merit Review Grant, (B90-166A) and a grant from the United States Olympic Foundation. The authors wish to thank the subjects for volunteering their time for this project.

Author Index

Abello, G., 297, 632
Adams, C., 254
Adams, K., 437, 446
Adams, T.C., 84
Agostini, Y., 508
Aimone, E., 195
Aitchison, J.R., 177
Akoumianakis, D., 431
Albright, S.J., 349
Ambrose, I., 65
Anderson, L., 212
Andre, J.M., 508
Apreleva, M., 349
Arce, G.R., 707
Arch, M., 620
Armitage, S., 16
Arnold, M., 118
Ashlock, G., 733
Axelson, P.W., 288, 314
Baglioni, P., 387
Bailey, C., 245, 248, 251
Bain, B.K., 56
Bamer, K.E., 707
Barrett, P., 530
Basu, S.K., 707
Bauer, L., 587
Beauchamp, R.D., 16
Bednarczyk, J.H., 743
Beitler, M.T., 490
Bell, A.C., 346
Bellik, Y., 455
BeMent, S, 670
Bender, R., 142
Bentz, B.D., 446
Benvenuto, P., 159
Berglund, D., 242
Berglund, L.A., 623
Bemier, B., 600
Bertocci, G.E., 311
Betz, R.R., 366, 369
Bhambhani, Y.N., 361
Bhaskaranand, N., 16
Birch, G.E., 673
Bond, A., 623
Boninger, M.L., 349, 358, 746, 755
Boone, D.A., 168, 220, 416
Boonzaier, D.A., 577
Borkowski, W.J., 678
Bourhis, G., 508
Bowes, D.R. 396
Bresler, M.I., 97
Brienza, D.M., 303, 325
Brock, L., 248
Brodie, J.K., 109
Brown, D.L., 381
Brugerolle, B., 508
Brule, A.J., 328
Buckley, S.M., 361
Bunnell, H.T., 678
Burbach, L., 262
Burger, D., 452
Bums, C.B., 369
Burrows, R.G., 505
Caims, A.Y., 109, 443
Calder, D., 68
Calhoun, G.L., 693, 696
Campbell, J.M., 393
Canilang, E.P., 156
Cardini, R., 632
Carlson, J.M., 611
Camey, D.M., 212
Camey, R.M., 92
Carson, M.C., 183
Cavalier, A., 207
Caves, K., 254
Cavin, R., 725
Chen, S., 481, 490
Chen-Wing, S.L.N., 629
Cheng, D.P.K., 267, 548
Chesney, D.A., 288, 314
Chester, D., 490
Chiu, E.Y.M., 215
Christensen, P.R., 375
Chu, C.S., 736
Chu, T., 171
Chung, K.C., 579
Chur, K., 620
Cincera, M., 632
Cleghom, W.L., 183, 189
Clift, D., 556
Cobb, C.B., 493
ColemaNesset, K.L., 168
Colucci, J., 407
Connell, B.R., 600
Cook, A.M., 106
Cooper, R.A., 186, 282, 349, 352, 355, 358, 746, 755
Cors, M., 603
Coutts, K.D., 749
Cracknell, J.F., 443
Cress, C.J., 115
Crouch, D.A., 372
Culver, C.F., 232
Cupo, M.E., 212

Currier, M., 106
D'Souza, W.C., 728
Da Pieve, V., 632
Dallmeijer, A.J., 752
Dann, E.E., 493
Dario, P., 323, 487, 511, 514
Day, K., 317
De Barmon, H., 508
Demasco, P., 124, 142
Dennis, F., 109
Devino, B., 285
Dion, B., 606
Dralle, A.J., 242
Dupuis, G.S., 306
Dupuis, J., 42, 103
Elder, G., 37
Enders, A., 584
Ensminger, G., 355, 358, 746, 755
Erlandson, R.F., 496, 551
Esten, G., 405
Evans, W.D., 264
Fagerberg, G., 62
Faghri, P.D., 396
Farrell, L.C., 556
Fass, D., 520
Fee, J.W., 502
Fee, L.J., 502
Fernie, G.R., 629
Ferrarin, M., 297, 387
Feyen, R., 733
Figoni, S.F., 696
Fishke, C., 257
Fleming, B.P., 200
Fleming, J.E., 200
Flotzinger, D., 690
Foohey, M.W., 725
Foster, M.J., 687
Foulds, R.A., 490, 710
Fraser, B., 205
Fredericks, T., 180
Frigo, C., 387
From, W., 317
Frye, E.M., 22
Furumasu, J., 320
Gaal, R., 81
Galatis, P., 464
Gehlot, N.L., 282, 303, 325
Genovese, V., 323, 487
Gent, A.N., 171
George, C., 92
George, K., 205
Gilden, D.B., 232
Gilmore, B., 207
Glaser, R.M., 396, 696
Glinert, E.P., 455
Glista, S.O., 472
Gogoulou, R., 467
Golly, S., 690
Gonzalez, J.G., 707
Gonzalez, J.P., 527
Goodwin, D.M., 618
Gosine, R.E., 177
Gradim Gericota, M., 133
Gray, J., 142
Gregor, P., 443
Gresser, J., 731
Grill, W.M., 717
Grott, R., 81
Grover, D.A., 94
Grupinski, S.G., 736
Gryfe, P., 118
Guadagnini, C., 511
Guerette, P., 320, 570, 594, 597
Guglielmelli, E., 487, 511, 514
Gunderson, J., 608
Guttman, M., 118
Hannah, R.E., 434, 499, 505
Harwin, W., 481, 517
Hassani, S., 396
Haugh, L., 165
Hawkins, J.R., 403
Hawkins, N.E., 403
Hazard, R.G., 165
Hearn, E.A., 611
Hedman, G., 31, 524
Heetderks, W.J., 659, 664
Heller, T., 28
Hensch, M., 437
Heredia, E.A., 707
Herman-Kilker, S.L., 59
Hershler, C., 177
Hignett, J., 100
Hilker, D.F., 59
Hillman, M.R., 279
Hobson, D.A., 87
Hochberg, L.R., 650
Hoehn, T., 603
Hoffer, J.A., 372, 375
Holt, D., 587
Hopman, M.T.E., 752
Hoskins, M.E., 538
Howell, R.D., 202
Hsu, L., 288
Huggins, Jane E., 670
Hughlett, N.S., 11, 259
Humphrey, D.R., 650
Hussey, S.M., 106
Huston, D.R., 337
Hwaung, G., 242
Iacuone, P., 387

Ide, M., 139
Ingle, D.F., 693, 696
Irwin, J., 626
Jackson, R.D., 484
Jacob, C., 28
Jang, H.D., 242
Jayachandran, V., 481
Jones, M.L., 594, 597
Joseph, A.W. 168, 220, 416
Joyce, A.W., 425
Jutai, J., 635
Kalcher, J., 690
Kallesoe, K., 372
Kamath, D.G., 16
Kamper, D.G., 84
Kang, T.E.T., 291
Kang, W., 75, 306, 308
Kauzlarich, J.J., 340
Kawaoka, P.Y., 154
Kazi, Z., 490
Kearney, B., 570
Kendrick, S.B., 570
Kilgore, K.L., 384
King, M.T., 94
Kirby, R.L., 343, 346
Kitto, K.L., 217
Knapp, R.B., 699, 702
Kobetic, R., 390
Koeneman, P.B., 736
Koester, H.H., 127, 714
Kolar, K.A., 22
Koumpis, A., 464
Kozicki, M.N., 545
Krass, A.E., 461
Krizack, M.L., 574
Krohe, J.G., 180
Kurtz, I., 118
Kushler, C.A., 94, 121
Kushwaha, R., 670
Laenger, C.J., 245, 248, 251
Lagerwall, T., 62
Lais, G., 611
Lam, D., 242
Lane, J.P., 228
Laschi, C., 511
Lauer, R.T., 384
Lechelt, E.C., 235
Lee, J., 248
Lefkowicz, A.T., 681
Letechipia, J.E., 22
Levine, S.P., 59, 127, 670, 714
Lewis, J., 449
Linden, M.A., 84
Lindsay, P.H., 592
Loepelmann, K.A., 235
Logan, G.D., 2
Longoria, Y., 245, 248, 251
Lorentzen, L., 262
Lou, S.Z., 579
Loubal, P.S., 232
Lourdes Lourenco, M., 133
Lown, N.F., 34
Lozac'h, Y., 331
Luebben, A.J., 410, 413
Lusted, H., 699
Lyons, R.F., 47
Mackenzie, T., 285
MacLeod, D.A., 343
Macomber, G., 168
Madill, H.M., 361
Maerz, D., 8
Mahoney, R.M., 422, 542
Mak, A.F.T., 291
Malassigne, P., 603
Mallik, K., 37
Malzahn, D., 162
Man, H.C., 291
Manikanta, M., 16
Mantuano, A., 323
Margolis, M.K., 262
Marina, K., 112
Marsden, R., 449
Marsolais, E.B., 390
Martins Ferreira, J.M., 133
Mason, S.G., 673
Mathews, D.E., 220, 416
Mattie, J.L., 499
Mayfield-Smith, K.L., 25
Maynard, E.M., 667
McAlpine, J. 130
McBride, M.E., 620
McCane, L., 684
McCoy, K.F., 124
McEachern, W.A., 484
McEwen, I., 300
McEwen, J., 174
McFarland, D.J., 645, 681, 684, 687
McGee, H., 334, 349
McKnight, C.P., 472
McLaurin, C.A., 78
McMillan, G.R., 693, 696
McNamara, A., 592
McNeal, D., 540
Meadows, P.M., 378, 393
Medeiros, J.M., 39
Mendelson, L.S., 28
Merbitz, C., 381
Messick, C., 570
Middendorf, M.S., 693, 696
Millar, D.M., 109

Miller, D.G., 556, 640
Miller, R., 242
Milner, M., 183
Mineo, B., 142
Mingrino, A., 387
Mockett, S.A., 257
Molino, L., 264
Moran, W., 570
Morrison, K., 109
Morse, M., 407
Mortimer, J.T., 717
Morton, P.E., 696
Moynahan, A.J., 422
Moynahan, M., 369
Mulcahey, M.J., 366
Mule, C., 514
Myers, D.R., 78
Nantais, T., 195
Nasman, V.T., 693
Naumann, S., 183, 189, 478, 728
Neuper, C., 690
Newell, A.F., 109
Nichols, D.R., 50
Nizio, P., 496
Nordhausen, C.T., 667
Normann, R.A., 667
Novak, M.E., 410, 413
O'Beirne, H., 728
O'Donnell, A.M., 45
Ohshima, J., 139
Okamura, L., 254
Okumura, R., 242
Osborn, S., 205
Owen, N., 81
Paris-Seeley, N.J., 174
Parker, D., 300
Parker, K.E., 189
Parnianpour, M., 152
Paskoff, G.R., 72
Patmore, D.W., 699, 702
Payette, M.J., 611
Peckham, P.H., 384
Pedotti, A., 297, 632
Peischi, D., 142
Pelegano, J.P., 5
Pennington, C.A. 124
Pepper, J., 195
Petty, L., 130
Pfaelzer, P., 81
Pfurtscheller, G., 690
Phalangas, A., 425
Phelps, J.A., 551
Piche, L.M., 618
Piech, R.S., 502
Pilkey, W.D., 75, 306, 308
Pino, D., 481
Pino, P., 508
Plyley, M., 195
Polando, G., 390
Polikoff, J.B., 678
Prabhu, D.F., 156
Prabhu, R., 16
Preble, J., 165
Pyfers, L., 443
Quesada, P.M., 192
Rabuffetti, M., 632
Radcliffe, D.F., 2
Rahman, T., 481, 517, 520, 707
Ramah, G.J., 676
Ramanathan, R., 517
Ramsay, C.D., 443
Rao, R.S., 159
Ratti, G., 323
Reddy, N.P., 156
Reed, R., 242
Reger, S.I., 84
Reid, D.T., 635
Reid, S., 165
Reinsel, T., 152
Richardson, P., 68
Ricketts, I.W., 443
Ridpath, C., 130, 419
Rippy, J., 496
Riviere, C.N., 440
Robertson, R.N., 186, 282, 352, 355, 358, 746, 755
Rodrigues, P.B., 273
Romilly, D.P., 174, 177
Ross, D.A., 670
Rovig, S.M., 611
Rowley, B.A., 626
Ryan, S.; 317
Saarnio, I., 223
Sabatini, A.M., 323, 487
Salganicoff, M., 481, 490
Sanders, J.E., 242
Sanford, J., 594, 597
Sant, D., 496
Savidis, A., 458
Sawyer, F.D., 192
Sax, C.L., 532
Schafer, C.L., 614
Schindler, S.M., 372
Schmidt, E.M., 659
Schnurer, J.H., 693, 696
Schuch, J., 5, 11
Schuh, L.A., 670
Schuyler, J.L., 542
Schwartz, A.B., 664
Schwartz, P.J., 53

767

Searle, I., 8
Seliktar, R., 159, 517, 520
Sfyrakis, M., 464
Shafer, D., 146
Shahoian, E.J., 232
Shapcott, N., 527
Shaw, G., 75, 78, 308
Shea, S.M., 567, 620
Sheredos, S.J. 212, 270, 493
Shimada, S.D., 355, 746
Shire, B., 130
Silva, A.F., 273
Silver, L., 130, 419
Silverman, M., 303
Simmet, N.A., 611
Simon, S., 152
Smith, B.C., 25
Smith, B.T., 366
Smith, D.G., 168, 220, 416
Smith, S.L., 294
Snell, E., 130, 419
Somerville, N., 540
Song, G., 294
Soto, P., 270
Sparto, P., 152
Specht, E., 225
Sposato, B.A., 31
Sprigle, S., 559
Stallard, A., 212
Stanger, C.A., 202
Steinfeld, E., 567
Stephanidis, C., 431, 458, 464, 467
Stewart, K.J., 186
Story, M.F., 594, 597
Strange, K.D., 372
Strojnik, P., 378
Stroud, S., 517
Sudarsan, S., 159
Sullivan, M.J.L., 475
Suryanarayanan, S., 156
Swords, M.E., 238, 535
Tam, E.W.C., 215
Taylor, B., 493
Taylor, J.B., 434
Tefft, D., 320
Tessier, D., 136
Thacker, J.G., 75, 306, 308, 340
Thakor, N.V., 440
Theis, J.W., 611
Thompson, B., 103, 112, 136
Thompson, D., 300
Todd, B.A., 294
Todd, M.A.C., 739
Tonack, M., 195
Toney, M.A., 300
Trachtman, L.H., 587
Tremblay, L., 331
Triolo, R.J., 390
Trudel, G., 346
Tumer, I.Y., 725
Turkiyyah, G., 242
Uffen, D., 728
Van der Loos, H.F.M., 146
van der Woude, L.H.V., 752
VanMeerdervoort, H.F.P., 396
VanSickle, D.P., 349, 352, 755
Van Winkle, D.L., 626
Vaughan, J., 195
Vaughan, T.M., 684,
Verburg, G., 478
Vitalitti, L.T., 14
Waldera, K.E., 564
Waller, A., 109
Walsky, E., 710
Watkins, M., 28
Weber, J.L., 19
Weisman, G., 337
West, K.L., 276
White, J., 245
Wiadnyana, K., 496
Williams, R.T., 538
Wilson, D., 540
Winston, P., 472
Winters, J.M., 149
Wisaksana, A., 478
Wise, G.B., 455
Wolpaw, J.R., 645, 681, 684, 687
Wong, L., 42, 349
Wright, W., 288
Yamamoto, T., 139
Yamashina, T., 139
Ye, N., 626
Zablocki, C.J., 603
Zickus, W.M., 124
Zuba, P., 428

BEST COPY AVAILABLE

RESNA

1700 N. Moore Street, Suite 1540
Arlington, VA 22209-1903
(703) 524-6686